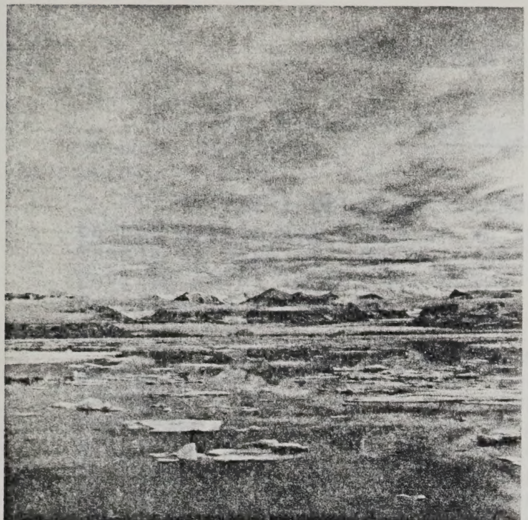
PETRO-CANADA

High Level

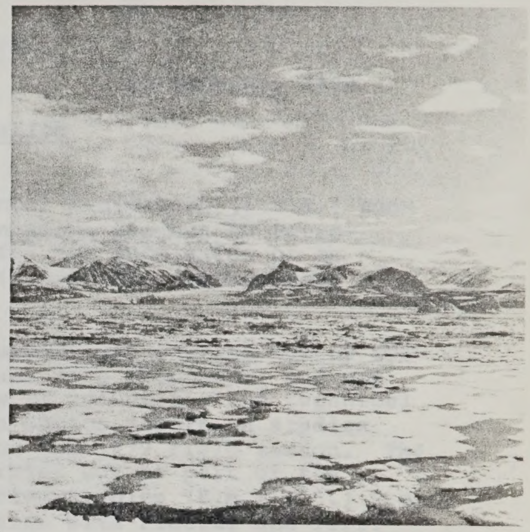
INITIAL ENVIRONMENTAL ASSESSMENT

PROPOSED BAFFIN BAY

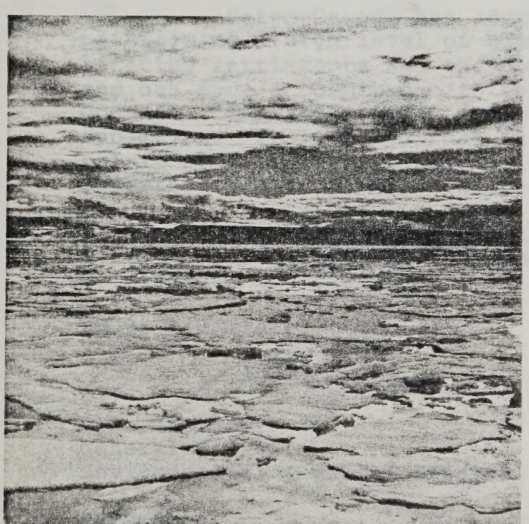
EXPLORATORY DRILLING PROGRAM



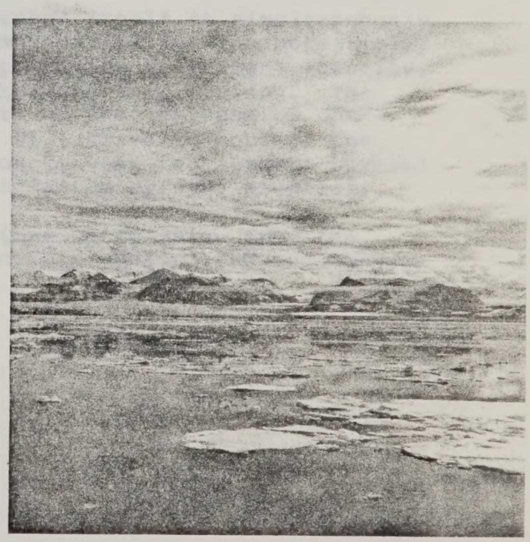
Northeast Bylot Island



Northeast Bylot Island
showing pack ice and icebergs



Cape Hay, Bylot Island



Northeast Bylot Island

(Photos R. Wallace)

Second Printing

Petro·Canada

12 February 1979

Declaration

The Initial Environmental Evaluation (I.E.A.) contained herein was begun as an in-house project by Petro-Canada as part of preparations for the submission of an Environmental Impact Statement (E.I.S.) for exploratory drilling in Baffin Bay.

The work for the Evaluation was carried out by consultants and staff of Petro-Canada (the Proponent) and was intended to serve as an overview of scientific and technical knowledge of the region and as a status report on studies either in progress or planned for the 1979 field season. The biological studies are being carried out as part of the Eastern Arctic Marine Environmental Studies (E.A.M.E.S.) Program and are planned in conjunction with Federal and Territorial Government officials.

Petro-Canada has addressed itself to simultaneously maintaining a high level of communication between potentially affected settlements and the appropriate Government agencies, and has made a commitment to enhancing this liaison. The document contained herein is part of that process of communiction. It is hoped that it will serve to enhance the spirit of scientific co-operation between the several parties concerned with, or potentially affected by, the proposal.

Any comments or questions which arise from the Initial Evaluation would be sincerely appreciated and should be directed to this office.

Yours sincerely,

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ACKNOWLEDGEMENTS

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Thanks and acknowledgements are extended to Norlands Petroleum Ltd., Calgary, Alta. for the use of data contained in support of their Environmental Impact Statement of June, 1978.

J. Davies, L. Lazic, M. Baden, S. Haider, H. Hume, B. Veldhoen, G. Leitch and J. Rowley contributed to the work. A. Tyler, P. Blackburn and K. Johnson typed the manuscript and typedrafts.

While the project was completed with the efforts of all of the above Petro-Canada assumes full responsibility for all the statements and data presented herein.

TABLE OF CONTENTS

1.0 OVERVIEW SUMMARY

1.1 OBJECTIVE

The Initial Environmental Assessment (IEA) detailed herein has been done so as to provide a summary review of the scientific and technical data of the Lancaster Sound - Baffin Bay region including details of current planning for offshore, exploratory drilling operations. It forms the basis for a formal Environmental Impact Statement (EIS) and it follows format and procedural guidelines set out by Government Agencies.

The Department of Indian Affairs and Northern Development (DIAND) requires that an EIS for environmental clearance be submitted by Proponents seeking authority to drill in Arctic waters. In the process Petro-Canada (the Proponent) refers the statement to DIAND (the Initiator) who then may refer it to the Department of Environment's Environmental Assessment and Review Process (EARP) for review. The EARP Panel subsequently makes recommendations on the proposal to the Minister of the Environment who then refers it to DIAND.

It should be clearly understood that the text contained herein is not an Environmental Impact Statment but is an attempt at initiating a rational dialogue about the environmental risks which may attend the proposed development.

It is considered that such a dialogue will assist both the Proponent and Regulatory Agencies in developing assessments of the proposal.

1.2 INTRODUCTION

In 1977 Petro-Canada acquired the permit acreage for Baffin Bay and more recently concluded a "farm-out" agreement for nearby acreage held by Shell Canada Resources Ltd.

At the time of the 1977 acquisition, the Honourable Minister of Indian Affairs and Northern Development set out the Eastern Arctic Marine Environmental Studies Program (EAMES). Petro-Canada, under this program of studies, carried out extensive field studies in 1978 and is preparing to continue this work in 1979.

The permit acreage in Baffin Bay of interest to Petro-Canada amounts to over 2.98 million acres (1.21×10^6 ha) on which over 8,000 km of offshore seismic studies have

been done. Large expenditures of funds are required to meet obligations incorporated into permit agreements. Work requirements in 1979 are $1.2 million ($0.40/acre) rising thereafter to $1.5 million ($0.50/acre). The permit expiration date (1983) on the acquired permit acreage formerly owned by Baffin Bay Petroleums requires a total expenditure of more than $6 million by that time. The required expenditure profile could be met only by an offshore drilling operation which would begin activities before 1983.

Revisions or delays to the permit obligations are considered to be counterproductive to stated Canadian objectives of frontier petroleum resource assessment.

1.3 THE NEED

Canada is projected to require substantial amounts of imported crude oil in the early 1980's. This conclusion is based upon detailed studies by Government agencies and is confirmed by a rapidly escalating trend toward imported oil. Price rises in this commodity, acting in concert with increasing volumes of oil which are being imported, have begun to exert a serious negative affect on the Canadian balance of trade.

It is the intent of Petro-Canada to begin exploratory drilling operations in Baffin Bay, as soon as it is feasible, so as to fulfill its mandate to promote the early assessment of frontier oil and gas resources in Canada. Baffin Bay is considered to potentially contain substantial offshore petroleum hydrocarbon reservoirs which, if proven and produced, could significantly contribute to the Canadian security of supply.

1.4 THE PROPOSED DRILLING PROGRAM

Petro-Canada presently proposes to commence offshore drilling operations during the open-water season of 1981. Dynamically-positioned drillships would be employed to drill 3 to 4 exploratory wells in a minimum of 4 years.

The Baffin Bay sedimentary basin is an ancient Tertiary-Cretaceous delta submerged in 300 - 900 m of ocean. The sedimentary deposits are in excess of 9,000 m deep. The depths of water in the proposed Baffin Bay drilling program range from 380 to 850 m. At least three, separate geological structures are proposed to be drilled from the dynamically-positioned drillship.

The operation would include the construction of an operations base at Pond Inlet and a floating, supply barge

moored near Devon Island. Supply vessels, fixed and rotary-wing aircraft and ice breakers will service the operation during the drilling season. At the end of the open-water season the ships would leave the region for southern port facilities.

Ice and weather surveillance systems are either in place or are in the process of development, as are navigational aids for the region.

1.5 PHYSICAL ENVIRONMENT

Studies of the existing physical environment of the Baffin Bay region began in 1978 and will continue this year (Appendix I).

Detailed coastal studies are in preparation with the intent of producing a systematic terrain and shoreline classification atlas. Atmospheric studies on regional climatology have begun and will be increasingly developed in concert with planning for the drilling proposals.

Ice studies, including historical reviews, are under way and are aimed at understanding the processes of ice movement in the region. Iceberg studies are part of this program of research and are designed to yield both regional and site-specific information. Marine geotechnical investigations on sediment structure and form (including earthquake zonations and ice scour) have been started and will be more fully elaborated in subsequent statements.

Physical and chemical oceanographic research begun in 1978 will be continued in 1979. Research on the water masses, ocean currents and tides have been intensively studied during the past field season.

Results from all these oceanographic and atmospheric studies will be incorporated into detailed simulations of potential impacts which may arise from the proposed exploratory drilling program.

1.6 BIOLOGICAL ENVIRONMENT

A recognition of the importance of the Lancaster Sound-Baffin Bay region to the ecology of the Eastern Canadian Arctic has been acknowledged by the type and degree of environmental studies carried out in 1978 and planned for 1979 (Appendix I).

Some bird colonies in the region represent significant proportions of avian communities of the Arctic or

larger, Canadian populations of the species. Of particular note are colonies of thick-billed murres, dovekies, black-legged kittiwakes, northern fulmars and eiders which occur in the region.

Over 33% and 85% of the North American populations of beluga and narwhal, respectively, occur in the region and substantive concentrations of other marine mammals (such as harp, bearded and ringed seals, walrus and polar bears) frequent the area. Killer whale and bowhead whale (the latter an endangered species) are also known here.

In short, the marine region in question supports a biologically rich community of many animal populations of national significance.

There are serious gaps in our knowledge of the dynamics of Arctic populations of marine mammals and birds. Scientists are only just beginning to understand the effects of natural climatic perturbations on population cycles and interactions of bird communities in the region. As such, it would be virtually impossible to construct a quantitative, predictive "impact analysis" except in the worst-case scenario of an incident which would result in massive mortalities of animals. Subtle, non-catastrophic impacts may significantly affect animal populations over the long-term however, predictive assessments of impacts cannot reasonably be attempted at this time. For instance, there is very little known about the effects of oil on populations of marine mammals, especially whales. Further, scientists have only just begun to properly enumerate regional species distributions and occurrences.

Extensive historical reviews of the impact of past commercial whaling operations are not available at present. It could be argued that such commercial ventures may represent the most substantive man-induced environmental impact in the history of the region. There is no question that current practises of harvesting marine mammals presently represents the most severe impact on regional populations.

1.7 POTENTIAL ENVIRONMENTAL IMPACTS

It is postulated that the proposed normal offshore drilling operations in Baffin Bay if properly controlled will not exert a significant impact on the biota of the region.

Worst-case scenarios for a gas blowout indicate that an uncontrolled flow of natural gas would most probably not exert a lasting impact on the biota. The possibilities

of a major blowout of oil are discussed in view of other, detailed studies and it is concluded that an oil blowout would be exceedingly unlikely to occur during exploratory drilling. If it did occur a significant ecological impact would probably arise from it, although one is limited by the restrictions of judgements on the nature and extent of the hypothetical incident. Certainly, marine bird colonies in the area would be seriously imperilled as could some marine mammal populations.

Presently, detailed oil-spill trajectory analyses and ice studies are in preparation and will result in the formulation of specific impact scenarios both as regard the proposed drilling operation and possible ecological impacts. Based on these and other studies oil spill contingency planning will be developed for submission to appropriate Government agencies.

1.8 SOCIO-ECONOMIC IMPACT

The proposal has tentatively indentified the air-strip extension, noise from increased air traffic, an increase in economic activity and alcohol consumption as changes resulting from a well ordered normal drilling operation. Significantly, the impact will occur in one community only and will be small when compared with a mining development or a land-based drilling operation.

The majority of the local population is of Inuit ancestry. They identify themselves closely with the land, sea and animals and continue to reap from the wildlife resource for sustenance, dietary preference and income in kind. A major oil blowout would therefore be of great economic, cultural and social consequence. Socio-economic and environmental issues are thus linked closely and the Proponent will deal with them in a holistic manner by inclusion of the Socio-Economic Impact Statement in the EIS.

2.0 THE PROJECT SETTING

2.1 DECLARATION AND OBJECTIVE

The Initial Environmental Assessment of proposed offshore, exploratory drilling in Lancaster Sound - Baffin Bay is not intended, in any way, to constitute a submission as an environmental impact statement.

The Initial Environmental Assessment, and the Environmental Impact Statement which will follow it, are restricted to considerations of the potential environmental impacts resulting from four exploratory wells to be drilled from dynamically-positioned vessels in Baffin Bay. No consideration is given to the possibility of subsequent hydrocarbon development activities beyond the exploratory phase as it is acknowledged that any further such activity would be considered as representing an entirely new phase of industrial development. This would require new, expanded social, economic and environmental assessments, field studies and environmental hearings so as to satisfy the current regulatory requirements of Canadian government departments responsible for the Arctic.

The intent of this Initial Assessment is three fold:

First: To review the amount and quality of environmental data for the Baffin Bay - Lancaster Sound region with a view to assessing the necessity for further studies and the adequacy of the present base of data.

Second: To begin a rational discussion about the environmental risks which attend the proposed development so as to better define specific areas of concern which may necessitate more detailed or expanded studies. Such a timely dialogue will assist both the proponent and the regulatory agencies in their assessments of the level of planning which will be necessary for the proposed drilling program.

Third: The initial assessment will serve as a basic working document in the formation of the expanded environmental impact statement presently in preparation.

Petro-Canada as operator is the proponent of exploratory offshore drilling in Lancaster Sound and Baffin Bay and has prepared the Initial Environmental Evaluation contained herein. Oil and Gas acreages in this region are held by Petro-Canada, Shell and Magnorth. The Initiator, the Department of Indian Affairs and Northern Development, main-

tains jurisdiction over this region and all others lying north of 60°N. latitude in Canadian territory.

Petro-Canada has undertaken scientific and technical research studies in the region and has compiled this Initial Environmental Assessment as part of a program to make public the findings of the research program which are available. Petro-Canada takes full responsibility for the contents of this Assessment which is intended to serve as an interim report on the research done or in progress. The research program is intended to serve as a basis for a regional drilling clearance for up to four exploratory wells.

The four main exploratory drilling sites under consideration by Petro-Canada lie within acreages which are to the south and east of Devon Island (Fig.2-1). Areas which could, potentially, be affected by drilling operations which are located farther south off the east coast of Baffin Island are not dealt with herein, but will form part of the Environmental Impact Statement which will be submitted as required by Federal regulatory agencies in concert with studies conducted under the Eastern Arctic Marine Environmental Studies (EAMES).

Four exploratory wells are proposed to be drilled in an exploratory program commencing during the 1981 open-water season at four locations (refer to Section 3):

Philpot	-	74°58'N	78°15'W
Bylot	-	74°30'N	79°05'W
Byam Martin	-	74°03'N	77°06'W
Jameson	-	74°05'N	77°45'W

In order to accomplish this commitment to offshore drilling, substantive financial and logistical arrangements must be in place no later than April 1980 if drilling is to be achieved by 1981. The terms and conditions of a drilling authority are required at the earliest possible time in order to permit incorporation of the conditions into the drilling planning process.

It is the intent of Petro-Canada to begin exploratory drilling operations in the region in order to fulfill a commitment by the Canadian government to "promote the early assessment of frontier oil and gas resources in Canada" as set out in Bill C-20 of the House of Commons. The sedimentary structures of Baffin Bay could contain significant reservoirs of petroleum which, if produced, might represent a critical supply of petroleum hydrocarbons within Canadian jurisdiction. Aside from the important considerations of

PETRO - CANADA ACREAGE

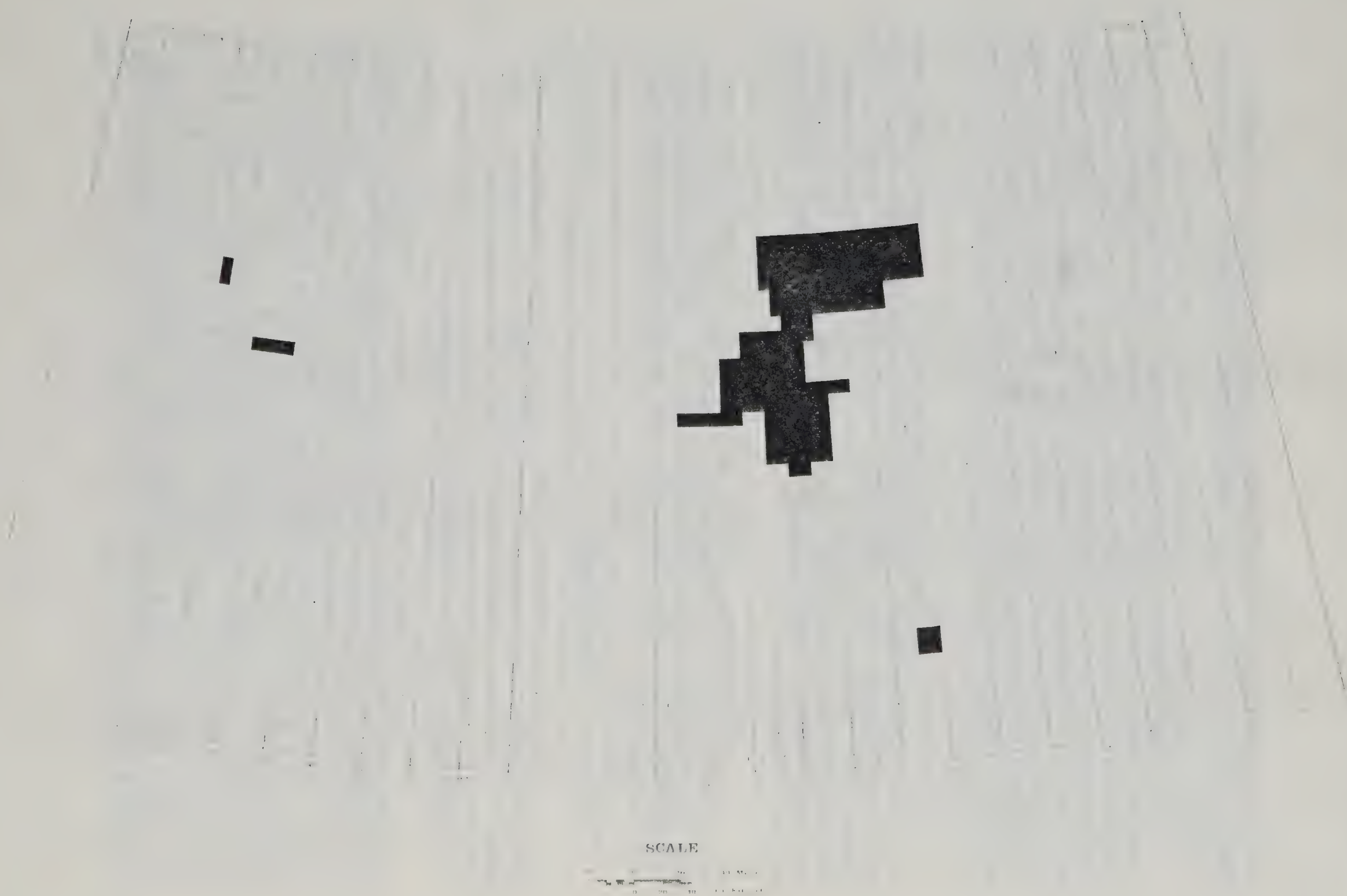

Figure 2-1

security of supply, significant discoveries in the region would act to offset a growing national deficit in petroleum trade.

The drilling program proposed by Petro-Canada would involve the commencement of exploratory operations during the open-water season of 1981 and could involve as many as four wells drilled over a period of 4 years or more by one or more drillships. Estimated costs for the proposed exploratory drilling program presently exceed $170 million. Pre-drilling expenditure commitments necessary to begin detailed planning of the proposed exploratory program are estimated to exceed $10 million.

It is proposed that in Year 1 of the proposed program the Byam Martin well would be completed and a start made at the Philpots site. In Year 2 the Bylot well would be completed and the Philpots well re-entered. Year 3 calls for the completion of the Philpots well and a start at the Jameson well site. Year 4 would see the re-entry and completion of the Jameson well.

If changes, due to unforeseen circumstances, are necessitated in the interests of safety during the proposed drilling schedule full consultation will be made with the appropriate regulatory agencies as is required by the drilling authority.

2.1.1 Background

In 1977 Petro-Canada acquired the permit acreage for the Baffin Bay region from Baffin Bay Petroleums. This acquisition was consistent with Canadian objectives for increasing the participation of national interests in an accelerating frontier exploratory program.

In 1977 the Honourable Minister of Indian Affairs and Northern Development initiated the Eastern Arctic Marine Environmental Studies Program. Petro-Canada has co-operated fully with the Government agencies and Advisory Committees of this Program, and has carried out extensive studies on the physical and biological environment of Baffin Bay and Lancaster Sound in conjunction with EAMES - related research and in concert with other industrial environmental research programs in the region. Field studies were started in the spring of 1978 and are slated to end in 1980 (Appendix I). If a drilling authority is received, appropriate monitoring programs will be designed and implimented throughout the time of field activity.

2.1.2. Statement on Purpose and Limits to the Exploratory Program

A permit for the proposed drilling program of four exploratory wells does not constitute an irrevocable commitment to intensive oil and gas development of the Baffin Bay Lancaster Sound region. It is the view of Petro-Canada that should production drilling be feasible or desirable a revised environmental impact assessment would be prepared and submitted to the appropriate regulatory agencies. The intent of the proposed drilling program is to examine the hydrocarbon-carbon producing potential of the offshore structures in the region as part of a national assessment of Canadian frontier resources. Should the geological structures in this underwater basin appear promising as regards the production and recovery of hydrocarbons from the region an entirely new series of environmental impact investigations would be carried out and submitted as part of the Environmental Assessment and Review Process of the Department of the Environment and for other, appropriate Federal regulatory agencies, such as the Department of Indian Affairs and Northern Development.[1]

These regulatory strictures and the published intent of Petro-Canada to undertake only a frontier exploratory program at this time, are the basis for the present submission ending with concerns for exploratory drilling. Production proposals would be considered as an entirely new development, planning of which would be subject to a further review and subsequent environmental studies as may be required.

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[1] The experience of lease sales in the northern, offshore U.S.A. should not be confused with the Canadian regulatory process. In the U.S. Court of Appeals State of Alaska vs. Kleppe *et al*. and Western Oil and Gas Association (No. 76-1829) the summary memorandum in support of motion for summary judgement (76-0368-Civil) against offshore oil and gas lease sales in the Gulf of Alaska a detailed analysis of the legality of the offshore lease sale was carried out. The plaintiffs noted that views expressed by the U.S. Department of Interior totally ignored the case of Union Oil v. Morton ...where the court found that, while the Department could indeed "adjust O.C.S. operations after issuing leases, and while the Department might even suspend lease operations for a *short* period of time, if it wished to deny lessees the right to profitably develop tracts subsequently determined to have been improvidently leased, it must seek special Con-

gressional action and full compensation. Thus, when exploration is completed, and lessees submit development plans to the Department, the Department is legally compelled to permit development on those tracts to proceed, even if the Department dramatically underestimated the environmental costs of such development when it originally issued the leases. In Canadian offshore resource jurisdiction such arguments do not apply. Lease sales and useage are strictly subject to an approvals process which addresses both drilling capabilities and environmental impacts. Indeed, the new Canada Oil and Gas Drilling Regulations significantly enhance the regulatory standards for offshore drilling operations.

These regulatory factors, added to the stated approach of Petro-Canada not to proceed until such time as significant environmental and social impacts have been adequately addressed, including field operations and contingency planning, combine to ensure that potential production developments after the proposed exploratory drilling program must be considered as an entirely new proposal.

2.2 THE NEED

2 2.1 Canada's Need to Test the Sedimentary Basin of the Northwest Passage (Baffin Bay Region)

The National Energy Board in 1977 produced a detailed study on Canadian oil supply and requirements until the ye r 1995. That forecast indicated a steady decline in the pr duction of Canadian light and heavy crude oils (Table 2-1). At the same time the Board foresaw a primary oil demand increase from an actual 1975 level of 3.5 quads (3.5 quadri lion Btu's) to 4.7 quads in 1985 to 5.5 quads in 1995 (an an ual average growth of 2.1 per cent over the forecast period . These figures indicated to the Board that in the "most ikely case" Canadian indigenous oil supply would fall short f requirements by about 4.5 x 10^5 barrels/day by 1995 a d that the shortfall would increase to around 6.0 x 10^5 ba rels/day in 1990-1995. In the most optimistic scenar o (low requirements and high supply forecasts) indigenous c l supply falls short of requirements by about 2.5 x 10^5 ba rels/day in 1985. On the other hand, the worst-case situat on (high requirements and low supply forecasts) indicate a shortfall of about 8.0 x 10^5 barrels/day (1.3 x 10^5 m^3 by 1985 and as much as 1.8 x 10^6 barrels/day (0.29 10^6 m^3) in 1995.

Energy, Mines and Resources published an "Energy Strate y for Canada" in 1977. In that document they estimated hat by 1985 net oil imports could amount to 47% of Canadi n energy demand by 1985 and 68% by 1990. The study noted hat progressively higher oil prices would stimulate fronti r oil production but cautioned that "...even under the high-p ice scenario it is possible that Canada could remain a subst tial net importer of oil through the 1976-1990 period, relyir on foreign suppliers for as much as 40% of our domestic de ands in 1985 and 38% in 1990." The results of such projec ed import levels was that the balance of trade in oil "...cc ld swing from a surplus of about $1.0 billion in 1974 to a ficit of about $4.5 billion by 1985." The latter (1977) estimate was probably rather conservative, as recent events have borne out, because it was based on the assumption of no ajor price increases for oil in global markets.

In any case, Canada is expected to require imported crude il in the early 1980's for markets now served by indigenous crude oil supplies. Current balance of payments imbalanc s would be aggravated by any increased requirements for th importation of steadily appreciating oil supplies. A curso examination of the trends of Canadian crude petroleum import since 1951 indicates a rapidly escalating trend toward i ports (Table 2-2).

Table 2-1.

Potential Producability from Established Crude Oil Reserves in Canada. (N.E.B. Forecast(1977).[millions barrels/day (millions m^3/day)].

Year	Total Light Crude Oil	Total Heavy Crude Oil	Total Crude Oil
1979	1.191 (0.19)	0.166 (0.03)	1.357 (0.22)
1980	1.046 (0.17)	0.148 (0.02)	1.195 (0.20)
1981	0.915 (0.15)	0.132 (0.02)	1.047 (0.17)
1982	0.801 (0.13)	0.118 (0.02)	0.919 (0.15)
1983	0.701 (0.11)	0.106 (0.02)	0.807 (0.13)
1984	0.616 (0.10)	0.095 (0.02)	0.711 (0.12)
1985	0.543 (0.09)	0.085 (0.01)	0.628 (0.10)
1986	0.481 (0.08)	0.076 (0.01)	0.557 (0.09)
1987	0.426 (0.07)	0.068 (0.01)	0.495 (0.08)
1988	0.379 (0.06)	0.061 (0.01)	0.441 (0.07)
1989	0.339 (0.06)	0.055 (0.009)	0.393 (0.06)
1990	0.303 (0.05)	0.049 (0.008)	0.352 (0.06)
1991	0.273 (0.04)	0.044 (0.007)	0.316 (0.05)
1992	0.245 (0.04)	0.039 (0.005)	0.285 (0.05)
1993	0.221 (0.04)	0.035 (0.005)	0.256 (0.04)
1994	0.200 (0.03)	0.031 (0.005)	0.231 (0.04)
1995	0.180 (0.03)	0.028 (0.004)	0.209 (0.04)

Table -2

Trends of Major Canadian Imports of Crude Petroleum by Country of Origin (m^3) (Adapted from Energy, Mines & Resources, 1978).

Countr	Years			
	1951	1961	1971	1976
U.S.S. .	-	-	-	164
Unitec Arab Emirates	-	-	-	838
Iran	-	1,923	5,606	9,595
Iraq	-	-	1,464	1,840
Kuwait	-	2,064	-	315
Libya	-	-	330	1,395
Saudi rabia	1,371	3,121	2,512	6,745
Yemen	-	-	-	2,789
Trucia States	-	-	474	-
Egypt, ..R.	-	-	-	129
Nigeri	-	-	3,176	1,909
Algeri	-	-	-	747
Frencl Africa, N.E.S.	-	-	-	125
Gabon	-	-	-	745
Ecuadc	21	-	-	131
Columl a	-	-	1,342	-
Venezi la	7,444	13,350	22,970	16,475
Trinic d	169	488	-	118
Mexicc	-	-	-	42
U.S.A.	3,730	120	-	120
Other	-	-	1,198	-
Totals	12,735	19,143	39,072	44,222

More recent project figures for supply and demand of natural gas indicate a firm established or potential supply base in Western Canada. The costs of development of gas production facilities in association with Lancaster Sound and Baffin Bay would be far in excess of that for comparative deliveries from Western Provinces at present, and it is therefore unlikely that gas production would occur in the near future even if exploration programs for reserves were successful. (This should not be confused with current, proposed gas production planning in association with Melville Island gas reserves potentially transportable by L.N.G. tankers). Hence, discussions here will be limited to the Canadian future requirement for expanded crude oil reserves.

In 1976 the Ministers of Indian Affairs and Northern Development and of Energy, Mines and Resources jointly set out a Statement of Policy on proposed Acts and Regulations designed so as to promote the early assessment of the frontier oil and gas resources of Canada (Bill C-20). A key aspect of the proposed legislation was the "need to know" about Canada's frontier petroleum resource base in order to diminish the growing national dependence on imported oil.

The Canadian Arctic is characterized by three primary (or potentially) petroliferous basins: The Beaufort, Sverdrup and Baffin Bay. The latter is unproven and unexplored, however, it is considered to be comparable in size and geology to the North Sea. Hence, it contains several geological structures which hold considerable promise as significant petroleum reservoirs. The basin is an ancient Tertiary-Cretaceous delta deposit containing several thousand of sediments now submerged in from 300 - 900 m of ocean water. Geological investigations on Bylot Island indicate that the sedimentary deposits are capable of containing petroleum at depths below 2100 m.

Petro-Canada is the major owner of acreage permits in the Lancaster Sound - Baffin Bay region (Table 2-3) holding 2.98 x 10^6 acres (1.2 x 10^6 ha) (38.2% of the total acreage leased). It is the intent of the Corporation to fulfill permit work requirements on the permit acreage, subject to the required approvals, in order to facilitate the assessment of Canada's frontier petroleum resources. The expected shortfall in Canada's oil reserves could be partially offset by the discovery of substantive, offshore Arctic reservoirs. These potential reservoirs could probably, if found and produced, make available oil to the regions of Canada which will constitute the bulk of imported oil requirements (east of the Ottawa Valley). Markets of strategic consequence could be

ble 2 3.

reage Summary - Lancaster Sound/Baffin Bay Region.

Cc pany	Permit Expiry Date	Acreage(ha) Held[millions] Total	(%)	Total Work Required ($ millions)	Total Work Done[1] ($ millions)
tro-C nada 7 per its)	1983	2.98 (1.20)	(38.2)	$7.88	$1.19
ell 0 per its)	1983	2.13 (0.86)	(27.3)	$5.65	$1.60
gnort 4 per its)	1981/1983	2.30 (0.93)	(29.5)	$6.13	$1.93
lf perm ts)	1983	0.28 (0.11)	(3.6)	$0.75	$0.21
xaco perm ts)	1983	0.11 (0.04)	(1.4)	$0.30	$0.08
		7.80 (3.14)	(100)	$20.71	$5.01

As o Sept. 1978.

potentially serviced by discoveries in the northeastern offshore region.

The objective of the activity assessed herein, however, relates solely to the exploratory drilling phase of development. No further development issues or consequences are to be touched upon at this time because any additional activities are considered to be the subject of separate, new application and assessment procedures. This proposal is solely a frontier, petroleum exploratory program to delineate the potential resources of the region.

It is recognized that if commercial reservoirs of petroleum are delineated any development programs would be exceedingly expensive. Imperial Oil et al. (1978) estimated that for the Davis Strait Region very large reservoirs, in the order of 500 million barrels, would have to be discovered for economic development. Reservoirs of this magnitude would be capable of producing about 1.0×10^5 barrels/day (0.16×10^5 m^3/day) would significantly add to the Canadian offshore oil production.

If that estimate applies to the Davis Strait region, as much or greater would certainly have to be proved for Baffin Bay before subsequent developmental activities could proceed. At least 10 years, or more, could elapse from the time that commercial reserves were fully delineated until any production activities commenced. Hence, even if substantial discoveries were made soon after regulatory clearances it is doubtful that any production from the reservoirs could begin before the early 1990's.

In summary, Petro-Canada considers that the Baffin Bay region contains a large number of structures which, if they contain oil, could significantly alter the Canadian petroleum reserve picture.

2.2.2 Proponents Work Obligations

Exploratory drilling programs in Baffin Bay are required as a result of expenditure profiles built into permit agreements binding the operator to increasing acreage work obligations over the permit term. Relatively large amounts of expenditure will soon be required if annual work obligations are to be met. Unless exploratory drilling programs are begun soon, legal work obligations will not be met unless exceptional steps are taken by regulatory agencies to extend the permit conditions.

Delays which would necessitate any such permit extensions or lapses are considered to be counterproductive to stated Canadian objectives for assessment of frontier petroleum basins. The very large expenditure profile associated with an exploratory drilling program in Baffin Bay would satisfy permit exploration requirements and objectives for frontier basin assessments.

2.3 ALTERNATIVES

2.3.1. No Drilling

Any balanced environmental assessment must, by definition, address a "no activity" alternative to the proposed development.

If exploratory drilling was not permitted for Baffin Bay it would not necessarily mean that man-made threats to the environment would be removed. Resource harvest patterns (as outlined later) would continue as would the associated shipping (sea and air) activities resulting from domestic, government and military operations in the region. There is the potential for increasing shipping activity through the Northwest Passage associated with resource extraction activities in the region (Lead-zinc shipments, fuel and material resupply, and possibly liquified natural gas (L.N.G.) shipments). It is interesting to note that in the past the major oil spillages in the Canadian eastern Arctic region have originated primarily from resupply or transport vessels (Table 2-4).

A decision against exploratory drilling in Baffin Bay would not allow for a fulfillment of stated Canadian government objectives to assess the frontier hydrocarbon resource potential in the region. Such a decision would also have the negative effect of discouraging future potential exploratory programs in associated frontier areas until such time as clarification of policy-level development decisions were made. It is, nevertheless, the position of Petro-Canada that no drilling activities would take place in Baffin Bay until such time as it had been clearly demonstrated that exploratory drilling could be done within acceptable limits of risk. A major portion of the predrilling investigation is aimed at determining the level of risk.

2.3.2. Delay the Drilling

Another possible scenario is that the proposed drilling program could be delayed for a specific or an indefinite period of time.

The Proponent contends that lengthy delays for further environmental studies or observations would not be reasonable because of the substantive amount of documentation in preparation or available in other, associated proposed developments. Also, continuing studies will be carried out throughout the lifetime of the project should an approval be received. The continuing studies represent a significant

Table 2-4.

Major Oil Spill Incidents in Canadian Eastern Arctic Region (1974-1978). (Adapted from E.P.S., personal communication).

Date	Place	Oil Type	Amount Spilled (1)
Aug. 2, 1974	Saglek, Lab.	Diesel	2,275,000
Sept.28, 1974	Mary's Harbour, Lab.	Diesel/Gasoline	5,460
Nov. 24, 1974	Fox Harbour, Lab.	Diesel	5,460
Jan. 2, 1975	Saglek, Lab.	Diesel	145,600
Oct. 27, 1975	Cartwright, Lab.	Diesel	6,370
Feb. 9, 1977	Makkovik, Lab.	Diesel	6,143
May 1, 1977	Davis Inlet, Lab.	Stove Oil	6,825
June 2, 1977	East of Square Is.,	Diesel	609,700
Sept.23, 1977	Nain, Lab.	Furnace Oil	2,730
Nov. 20, 1978	Cartwright, Lab.	Gasoline	27,300
			3,090,588

commitment to Arctic research which would not otherwise be available to the Canadian scientific community.

No amount of continued environmental survey studies will alter the threat from an uncontrolled release of oil. The drilling technology which will be brought to the area, should approval be received, will represent the best practical ability to complete the proposed exploratory program. While it could be argued that delays in the proposed drilling could allow for significant improvements in oil spill cleanup methodologies, it is the view of the Proponent that no significant advantages would accrue from any delays.

2.3.3. Alternative Methods of Drilling

A dynamically-positioned drillship (of the specifications cited later) is the only drilling system which has the capability to operate in the depths of water and ice conditions known for Baffin Bay.

Ice movements in the region prevent any consideration of ice-strengthened platform drilling. No consideration is given to production or development activities beyond the exploratory drilling phase as further programs beyond the proposed exploratory wells would be the subject of new studies and submissions by the Proponent. Here, approval is sought for only this, specific exploratory program to assess the frontier, Baffin Bay basin.

2.3.4. Alternative Locations for Supply Bases

A prime consideration for the selection of supply bases in the high Arctic rests with the availability of transportation (shipping and air), communications and housing facilities near the site. A shore base must lie within helicopter or fixed-wing flight ranges from the drillship, and adequate capabilities must be present for sustained, routine or emergency supply operations.

The Proponent considers that a major shore base could be located near Pond Inlet, however, discussions are now in progress with community and government personnel to ensure that any works would be done with minimal impact on the environment or community. Most supplies will be carried to the drill site on board the drillship which will be provisioned before sailing north. Fuel and fresh water resupply methods are also under study (Section 3).

2.4 RELATED ACTIVITIES

Activities related to the program of exploration drilling, such as seismic surveys and environmental monitoring studies, would be carried out throughout the duration of the drilling. The degree and kinds of these activities will be determined by the level of intensity of the drilling and the locations in which it is done.

Promising discoveries, which might be made during the course of exploratory drilling, would necessitate engineering design studies on possible production facilities and techniques for transport of the petroleum reserves to recovery locations. At the same time completely new environmental assessments would commence as part of an expanded feasibility study of production. As production facilities would require extensive engineering design ample time would be available for renewed assessments on the environmental acceptance of such plans in concert with the required regulatory approvals process. It is estimated that up to 20 years could elapse from the time that any significant discoveries of oil are proven (if any) until they could be produced and transported to the south.

REFERENCES

Energy, Mines and Resources Canada, 1978. Oil and Natural Gas Industries in Canada, 1978. Rept. ER 78-2, Ottawa, Ont., 104 pp.

Energy, Mines and Resources Canada, 1977. An Energy Strategy for Canada. Policies for self-reliance. Ottawa, Canada. 170 pp.

Environmental Protection Service, Personal communication. Letter from Dr. C. Duerden, Environ. Emergency Div., Halifax.

Imperial Oil, Ltd., Aquitaine Co. of Canada, Ltd., and Canada-Cities Service, Ltd. 1978. Environmental Impact Statement for Exploratory drilling in Davis Strait Region.

National Energy Board of Canada (1977). Canadian Oil Supply and Requirements. Ottawa, Canada. 156 pp.

3.0 THE PROPOSAL

3.1 INTRODUCTION

Here, it is the intent of the Proponent, to review plans for the drilling of up to four exploratory wells in Baffin Bay. The presentation made is intended only as a summary exposition of the logistical requirements entailed in an Arctic, offshore drilling program.

The Drilling Authority and Drilling Program Approvals will be sought upon completion of the detailed planning phase of the operations. Petro-Canada is presently examining several different types of drilling systems most suitable for the Baffin Bay region and planning for the necessary support facilities is, therefore, at a preliminary stage of development.

A formal, detailed presentation of all the aspects involved in carrying out and ensuring an efficient, safe drilling program will be submitted in concert with environmental statements at a later date. Throughout, adherence will be maintained to the Canada Oil and Gas Regulations and other pertinent legislation administered on the Federal Lands involved in the exploration program.

3.2 THE DRILLING SITES

Table 3-1 indicates the locations currently proposed for drilling in the exploratory program. The sites are located in Eastern Lancaster Sound and the North-Western Continental Shelf region of Baffin Bay. At these locations geological investigations indicate promise for significant hydrocarbon reservoirs in sedimentary zones lying more than approximately 1,500 m below the ocean floor.

Preliminary planning by Petro-Canada calls for the use of one drilling vessel which would drill and evaluate one, or possibly two, wells during the open-water season. Any partially-completed wells would be completed and evaluated during subsequent drilling seasons. As the basic program design calls for the drilling of only one well per season, four years have been allocated to the drilling program. Actual drilling progress and conditions at the site will determine if secondary drilling operations will be attempted in any given year.

Table 3-1.

Proposed drilling locations for Baffin Bay - Lancaster Sound.

Site Designation	Latitude	Longitude	Drilling Depth (m)[1]	Water Depth (m)
Philpot	74°58'	78°15'	2650	380
Bylot	74°30'	79°05'	1520	610
Byam Martin	74°03'	77°06'	2380	840
Jameson	74°05'	81°30'	2990	850

1 Approximate: Estimated from M.S.L.

3.3 DRILLING CONCEPTS

The drilling operation is presently perceived as being a task force made up of a drillship, supply vessels and supply barge escorted, if necessary, by an icebreaker to the drilling zone from approximately the middle of July until early October. The selection of the first drill site will be based on a series of factors such as ice frequency-probability functions and water depth as related to scour. The initial well attempted will be chosen on the basis of security from ice impingement, currents (as potentially affecting the movement or dispersion of pollutants) and weather. Safety will, therefore, be a prime consideration in the initial site selection. As drilling proceeds, the experience gained at relatively secure sites will be applied to those which may be more difficult to drill.

When the well is completed, or at the end of the drilling season, the task force will leave the region for southern ports. Throughout the time of the drilling operation support services will be provided chiefly by air via from the supply barge and through Pond Inlet.

3.4 EXPLORATION DRILLING EQUIPMENT

The choice of the appropriate drillship is a critical consideration in the formation of an Arctic drilling fleet. The principal criteria in the selection of this vessel will be based on factors such as the type of drilling rig and the equipment on the ship and ocean-going stability and resilience to damage. The automatic control system used to maintain the position of the vessel will also be critically reviewed before the final selection of a dynamically-positioned drillship is made. Presently, several types are under consideration (Table 3-2).

A dynamically-positioned floating drilling unit will be employed in the operation. This type of rig is capable of maintaining a most favourable heading and of quickly moving off location in the event of surface environmental problems.

The primary position reference system under consideration is accoustic. The system is generally made up of several transponders at the sea floor. Hydrophones located on the underside of the hull receive the signals and the information is processed by two, independent ship-borne digital computers. Suitable backup positioning systems, such as riser angle indicators, will be employed.

Table 3-2.

List of drillships under consideration for potential use in Baffin Bay (A) and those presently available (B).

A.

VESSEL NAME	WATER DEPTH CAPABILITY	OWNER
Ben Ocean Lancer	900 m.	Odeco/Ben Line Offshore
Discover Seven Seas	1300 m.	The Offshore Company
Neddrill II	600 m.	Neddrill
Pacnorse I	900 m.	Pacnorse Drilling Corp.
Pelerin	1000 m.	Helmer Staubo & Co.
Pelican	600 m.	Foramer
Penguin	1300 m.	I.H.C. Holland (Under Construction)
Petrel	900 m.	Offshore Europe N.V. (Foramer)
Sedco 471	1300 m.	Overseas Drilling Ltd.

B.

VESSEL NAME	LENGTH O.A.	BEAM	DRAFT	LIGHTSHIP DWT	POWER	YEAR BUILT
	(METRES)	(METRES)	(METRES)	(TONNES)	(KW)	
Ben Ocean Lancer	149	23.5	12.5	8,500	12,000	1977
Neddrill II	165	27.4	13.1	15,000	17,700	1977
Pacnorse I	169	23.5	12.5	8,500	12,000	1979
Pelerin	148	23.5	12.4	8,800	12,000	1976
Pelican	149	21.4	12.5	7,300	8,500	1972

3.5 NORMAL DRILLING OPERATIONS

3.5.1. Previous Experience in Offshore Drilling

Deep water drilling from dynamically-positioned drillships has been carried out throughout the world for about a decade. While the exact drillship type to be used in Baffin Bay has not, as yet, been selected by Petro-Canada there is a considerable body of data available on the success with which these vessels have been employed.

Milne and Smiley (1978) noted that since 1968 more than 150 offshore wells have been drilled in water depths exceeding 180 m around the world, of which 15 were drilled in depths exceeding 600 m.

The depths of water in the Baffin Bay drilling program range from about 380 m to 850 m (Table 3-3). In 1973 and 1974 Shell extended the offshore drilling record beyond 600 m and Exxon established a deep-water world record with a well drilled in 1,054 m of water off Thailand (Norlands, 1978). Affiliates of Imperial Oil have, in the same region, drilled other wells at water depths of 580 m, 760 m, 900 m and 1,052 m (Imperial Oil Ltd., et al.,1978).

Vessels constructed by IHC Holland (the Pelican, Havdrill, Petrel and Pelerin) have had significant success in dynamically-positioned drilling, the latter having successfully drilled in 900 m of water (Imperial Oil Ltd., et al., 1978). Drillships now under construction will provide a drilling capability for water depths of 1,500 m by 1980.

In 1976 a dynamically-positioned drillship, the Pelican, drilled the first well in a series of five off the coast of West Greenland (east of Cape Dyer, Baffin Island) in 179 m of water. Further south, off the coast of Labrador, 8 wells have been completed in water depths ranging from 140-310 m using dynamically-positioned drillships.

3.5.2. Drilling Procedures

Drilling, casing, cementing and logging plans will be developed in the drilling program so as to be specifically tailored for each particular well location. Petro-Canada will be intensifying site-specific surveys in the vicinities of the well-sites and will eventually establish beacons at them. Specific details of the riser, BOP and casing program will be provided in the environmental impact statement in preparation, as will an assessment of drilling hazards and procedures to circumvent them.

Table 3-3

Drilling Prospects in Bylot Baffin/North Baffin Bay

STRUCTURE	LATITUDE	LONGITUDE	W.D. METRE	DRILLING DEPTH FROM MSL METRE	DEPTH TO BASEMENT FROM MSL METRE
PHILPOT	74°58'	78°15'	380	3200	3000
BYLOT	74°30'	79°05'	610	2000	1700
BYAM MARTIN	74°03'	77°06'	840	3400	3200
JAMESON	74°05'	77°45'	850	3700	3500

Petro-Canada proposes to explore at least three separate geological structures in Baffin Bay which will necessitate at least four separate wells. If there is absolutely no encouragement of any hydrocarbon potential in those basins, the exploration drilling program will cease after the third well. If a significant find is made, or if some encouragement as to the presence of hydrocarbons is forthcoming from the three wells, it is possible that further wells would be attempted.

The procedures to be followed after the exploratory program of three or four wells will be determined by the findings of the exploratory program. Any subsequent programs of drilling are considered by Petro-Canada to be entirely separate from the proposed exploratory program and, therefore, subject to assessment and approvals. Obviously, if a future delineation program is warranted, more informed discussions would be possible at that time than are now feasible as substantial drilling experience and findings regarding the petroleum reservoirs would be available. The assessment for possible approvals would be a separate procedure subject to regulatory requirements. No development drilling, beyond that proposed for the exploratory program, would be attempted until such time as all the necessary approvals had been received.

3.5.3 Support Operations

The drilling locations under consideration are such that there is no major Canadian harbour or port north of St. John's, Newfoundland, which could be used to service the region. As lines of supply and communications would, therefore, be unacceptably long it is considered that the Baffin Bay drilling program must be essentially self-contained in the region.

Presently, planning calls for the construction of a shore base at Pond Inlet which will serve as a staging area for the transfer of personnel from the south (by air) and the drillship. The proposed facilities to be located at Pond Inlet would be sufficient to briefly house personnel while they are in transit. Facilities for up to 60 people are planned (to allow for sufficient accommodation in case of inclement weather or emergency situations) with a permanent staff operating the base around the clock.

A large, floating supply base will directly support the drilling operation. As the use of existing harbours on Baffin, Bylot and Devon Islands would not provide the continuous support and logistical availability required by the proposed drilling operation the floating supply base would be located near Devon Island.

The floating supply base would be a converted ice-strengthened barge carrying fuel, fresh water, bulk drilling supplies and stand-by riser. The base would be positioned from a southern port and moored at a suitable location as near to the drilling site as is feasible. Several potential sites are now under consideration and will be detailed in subsequent submissions.

A small crew would continuously man the base which would provide a valuable emergency facility for rotary-wing aircraft or other shipping operating in the region. Personnel will be transferred by helicopter from the Pond Inlet shore base, as soon as is reasonably possible, to the drillship or the floating base near it. The floating base consisting of a barge of from 12,000 tons dead weight would be ice-strengthened and converted to carry fuel (3,000 tons) in centre tanks and water (5,000 - 8,000 tons) in outer tanks. Bulk drilling mud components (800 tons), back-up or emergency equipment (such as replacement BOP stacks) and a stand-by riser could be stored on deck. A helicopter landing pad and refuelling area would be provided along with crew accommodation and transfer facilities. In addition, smaller offshore supply vessels would be used between the supply barge and the drillship. Design specifications for these vessels are under consideration (Table 3-4).

Small weather or ice surveillance stations would be required throughout the region during the drilling season and would be located at appropriate land sites. Several locations are now under consideration. A fully airborne ice and iceberg surveillance system would be flown out of Pond Inlet. The airborne surveillance system would be augmented by shore-based radar facilities based on one of Devon Island's eastern promentaries for optimal line-of-sight operation.

Communication lines between the drillship, supply base and Pond Inlet base would be maintained via satellite from each base to Calgary. Additional telephone and data links will be provided as well. Operational communications links will be provided between the vessels, aircraft and bases by UHF and VHF radio links. Navigation systems, such as OMEGA and ARGOS, will probably be augmented by a portable shore-based positioning system.

Table 3-4

Typical Offshore Supply Vessel Specifications

Classification: Ice Class: AWPPA Class C

Length O.A.	56 meters
Breadth Moulded	11.5 meters
Depth Moulded	5.0 meters
Draft	4.1 meters
Freeboard	0.7 meters
Gross Tonnage GRT	450 tonnes
Net Tonnage NRT	135 tonnes
Deck L X B	30 m X 10 x
Deck Cargo Capacity	450 tonnes
Bulk tanks	4 X 28.5 cu m.
Tank Capacities	
Portable Water	160 m ton
Drill Water	550 m ton
Fuel Oil	400 m ton
Bollard Pull	63 tonnes
Towing Winch	300 HP
Maximum Pull-First Layer	90.80 tonnes
Engine:	2 X 2875 BHP
Cruising Speed:	14 knots
Bow Thruster	300 BHP
Auxiliaries	3 Generators Total 400 KVA

The establishment of the regional support facilities will require that a sea-lift be carried out in 1980 (Fig.3-1). The weather stations and ice surveillance bases would be constructed during the 1980 summer season along with the shore base which include accommodation and communications facilities, at Pond Inlet. Improvements to the airstrip at Pond Inlet may also be required.

Marine support requirements include the operation of supply boats, ice-breakers and vessels for towing of icebergs. The supply vessels will be ice-strengthened and will support the drillship by transferring fuel, drilling supplies and other consumable items to it as may be required. The supply vessels will also provide capabilities which may include the towing of icebergs from the immediate vicinity of the drillship wherever possible. Ice breaking service may be required to allow access to the site early in the season.

Although as many as three flights per week may be made by passenger-freighter aircraft from Montreal and secondary local flights may be made from Nanisivik, Resolute and Frobisher Bay, the core of logistical air operations will be by helicopter (S 61N and Bell 212). It is anticipated that there will be at least one flight per day between the Pond Inlet base and the floating supply base or the drillship. All landing areas will be equipped with certified beacons and landing systems as required by the M.O.T.

3.5.4. Personnel

Petro-Canada will initiate intensive training programs for all personnel involved in the drilling operation. By 1981, the Petro-Canada personnel involved in communication and logistical support operations will have had three years of experience at shore stations in Pond Inlet and the surrounding satellite research stations on Baffin, Bylot, Devon and Coberg Islands and on research vessels.

Petro-Canada intends to place only highly trained, experienced drilling personnel in the field in recognition of the need to conduct an exceedingly safe drilling practise.

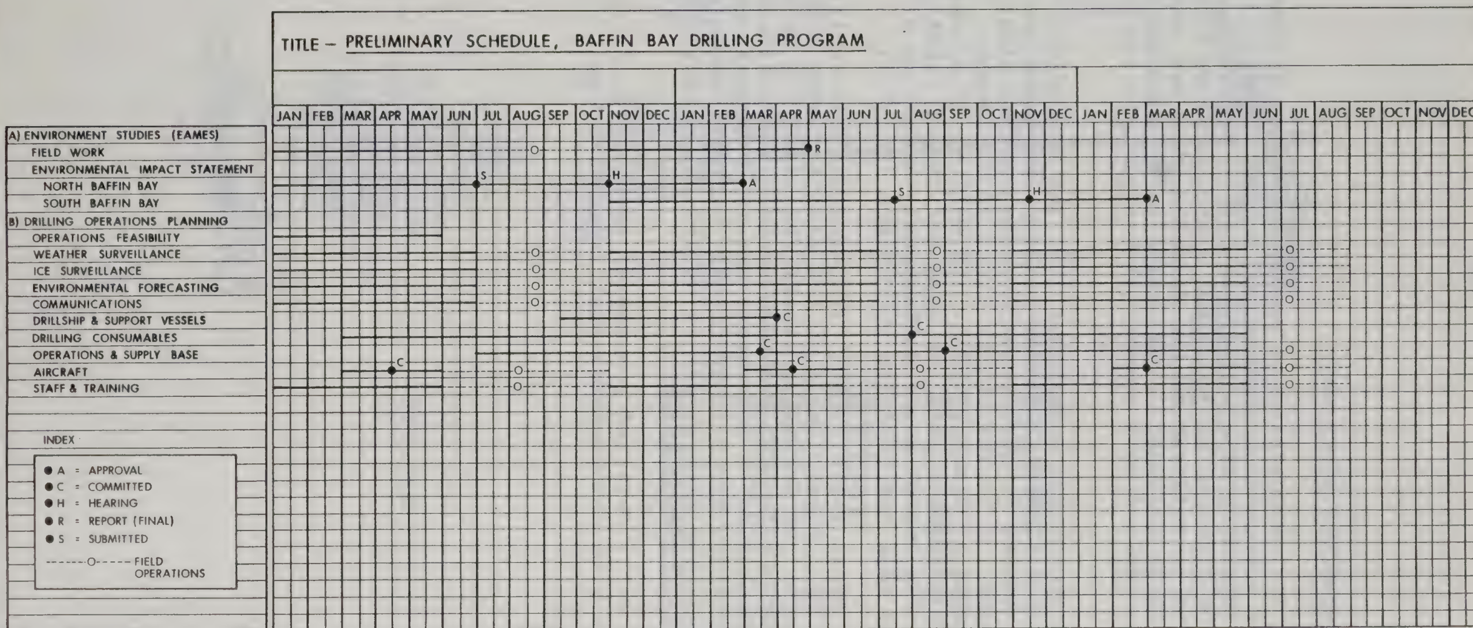

TITLE – PRELIMINARY SCHEDULE, BAFFIN BAY DRILLING PROGRAM
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
A) ENVIRONMENT STUDIES (EAMES)
FIELD WORK
ENVIRONMENTAL IMPACT STATEMENT
NORTH BAFFIN BAY
SOUTH BAFFIN BAY
B) DRILLING OPERATIONS PLANNING
OPERATIONS FEASIBILITY
WEATHER SURVEILLANCE
ICE SURVEILLANCE
ENVIRONMENTAL FORECASTING
COMMUNICATIONS
DRILLSHIP & SUPPORT VESSELS
DRILLING CONSUMABLES
OPERATIONS & SUPPLY BASE
AIRCRAFT
STAFF & TRAINING
INDEX
A = APPROVAL
C = COMMITTED
H = HEARING
R = REPORT (FINAL)
S = SUBMITTED
FIELD OPERATIONS

Fig. 3-1

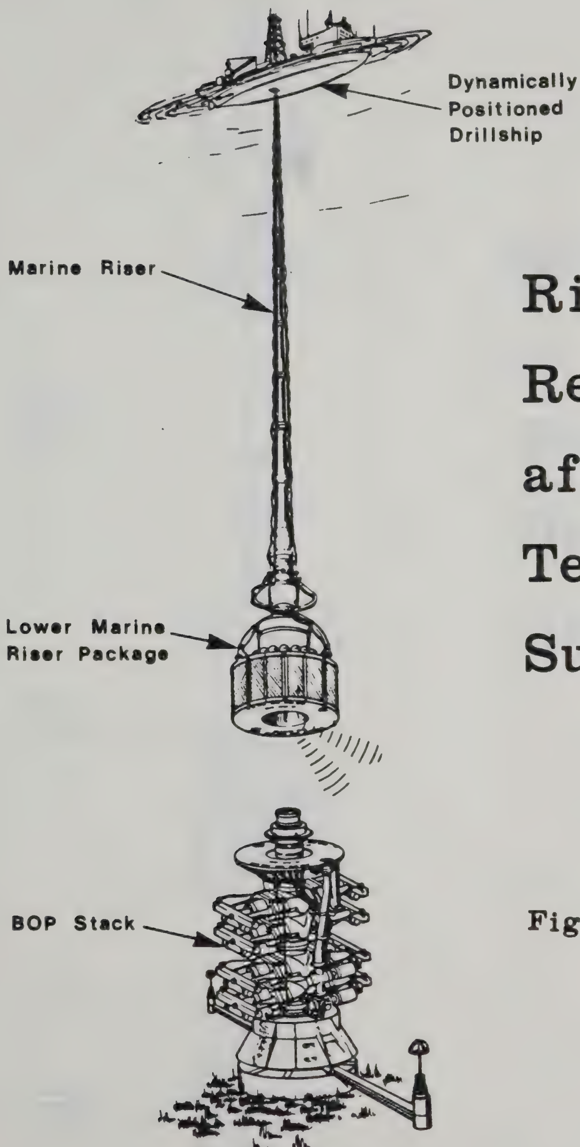
3.6 EMERGENCY PROCEDURES

A full exposition of procedures to be followed in the event of emergencies encountered during the drilling operation, including countermeasures, is in preparation. Details will be provided as to normal abandonment or suspension procedures to be followed at the drilling site and emergency procedures to be followed in the event of an approach by ice or icebergs. Relief well capabilities will be fully presented.

Petro-Canada recognises that the use of a dynamically-positioned drillship greatly increases the flexibility of response to unforeseen problems and eliminates the risk of losing the vessel in the event of a blowout. The ship could rapidly disengage from the well if it proved to be necessary or if approaching ice made moving off location necessary. The vessel could subsequently return to either re-enter the well and continue operations (Fig.3-2).

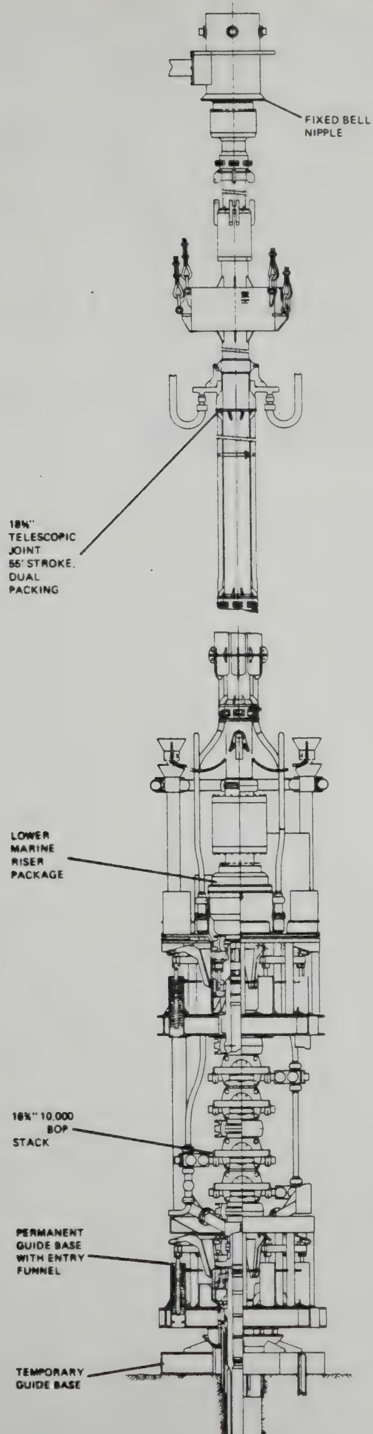
A spare B.O.P. stack, second riser and drilling consumables will be available on the floating base near the drillship or on the drillship itself (Fig.3-3). A backup capability in the form of a second dynamically-positioned drillship identified in subsequent detailed submissions. Further, operating times in Baffin Bay will be scheduled so as to maximize the time available at the end of the season for potential contingency work.

A full, detailed account of these basic plans will be submitted with the Environmental Impact Statement.



Riser Re-connection after Temporary Suspension

Fig. 3-2



Schematic of Subsea Drilling System

Fig. 3-3

REFERENCES

Imperial Oil Ltd., Aquitaine Co. of Canada, Ltd., and Canada-Cities Service, Ltd. 1978. Environmental Impact Statement for exploratory drilling in Davis Strait Region.

Milne, A.R. and Smiley, B.D. 1978. Offshore drilling in Lancaster Sound: Possible Environmental Hazards. Ms. Rept., Inst. Ocean Sci., Sidney, B.C., 95 pp.

Norlands Petroleums, Ltd. 1978. Environmental Impact Statement for exploratory drilling in the Lancaster Sound Region.

4.0 DESCRIPTION OF THE EXISTING ENVIRONMENT

4.1 PHYSICAL ENVIRONMENT

4.1.1 Coastal Studies

4.1.1.1 Introduction

Detailed coastal studies, in the region potentially affected by offshore drilling, have been done so as to predict sensitive areas to oil spills and associated disturbances. The studies are, as yet, incomplete, however, they are slated to continue and include field verifications wherever possible. This work will culminate with an Environmental Atlas. Details on the present state of development of that Atlas are outlined below.

Coastal studies of N. and N.E. Baffin, Bylot and S.E. Devon Island include two types of mapping based on airphoto interpretation: (1) detailed photo interpretation of surficial deposits and bedrock types of a narrow area (approximately 1 km wide) along the coast; and (2) is an attempt to map and classify beaches and beach sediments in the coastal zones of these islands.

Prior to the field season in the summer of 1978, aerial photo interpretation and posting of interpreted data on maps at a scale of 1:100,000 was completed. However a scale of 1:250,000 was adapted as a base for the final presentation, because of the size and number of 1:100,000 maps included in this project. Relatively large-scale morphologic units permitted the use of 1:250,000 maps, although restrictions were necessary in presenting small units, such as alluvial fan and talus deposits.

4.1.1.2 Terrain and Shoreline Classification

Systematic studies of terrain and shorelines of Baffin, Bylot and Devon Islands were done based on airphoto interpretation. A limited amount of detailed field work was done by a Geological Survey of Canada (G.S.C.) field party at five sites which were identified as representative of this region.

4.1.1.3 Terrain Classification

G.S.C. terrain classification used for mapping Somerset Island was adopted because of the proximity of this island to the area mapped for this project. The classifi-

cation allows adequate detailed or generalized descriptions of different morphologic units mapped on this scale. A primary subdivision was made by grouping related sediments into generic categories. The generic categories used are: alluvial (active and inactive), colluvial, deltaic, glaciofluvial, ice-contact outwash, marine, morainal and bedrock. Generic categories are indicated by an upper case letter beginning each word. The secondary subdivision was based on the morphology of each terrain unit. The morphologic modifiers used are: plain, rolling terrain, hummocky, ridged, terraced, kettled, fan, veneer, channeled and raised beaches. Morphologic modifiers are placed behind genetic categories, and are presented by a low cased letter beginning each word.

Extensive areas of exposed bedrock of sedimentary origin, crystalline - granitoid and gneissic rocks, volcanics and numerous gabbro dykes are found throughout the studied area. Because of the diversity of exposed bedrock, lithologic modifiers were introduced in the legend of the maps in preparation. Lithologic modifiers used are: carbonate, granite, gneiss, shale, quartzite, sandstone, siltstone and volcanic. Lithologic modifiers are identified on the maps by a low case letter placed in the upper left corner of the letter "R" indicating bedrock.

In the map series in preparation for the Atlas, terrain units used are either single units or complex units of two or more single deposits. The single deposits are identified on the maps by a label consisting of a lower case letter indicating texture; upper case letter indicating genetic category, followed by a lower case letter indicating morphologic category.

> Example: g,sAt - gravel and sand in an alluvial terrace. Complex units are identified by combination of two or more single units. A horizontal line between units indicates veneer of unconsolidated deposits (3-10 ft. thick) over the main terrain type. A vertical and a dash line identify the percentage of single units in a complex terrain form.

4.1.1.4 Shoreline Classification

The shoreline classification of the G.S.C. Coastal Research Group was adopted for this project. In general, two types of coastal zones have been identified by this classification: one constructed in bedrock and one constructed in unconsolidated deposits. The slope of immediate backshore areas was defined as steep, moderate and low.

Present beaches are classified as continuous and pocket beaches; material present in the beaches was classified as: boulders, gravel and sand. Offshore boulder barriers have not been noticed on aerial photographs, except in an area at the mouth of Narpaing Fiord, still in doubt because of lack of field verification.

Unfortunately, very little is known about beach processes in the Arctic and the data obtained so far are limited to few sources of information. Our knowledge of size variation in beach material is derived from slides and descriptions obtained from the G.S.C. field party.

4.1.1.5 Baffin Island

The topography of Baffin Island varies, including rugged mountains and flat lowlands. Three major physio- graphic divisions are recognized in the area studied (Fig.4-1).

1. Davis Highlands
2. Baffin Coastal Plain
3. Lancaster Plateau

The Davis Highlands extend approximately in a NW-SE direction, and dominate the eastern part of Devon, Bylot and Baffin Island. They are a belt of deeply dissected mountains, penetrated by long fjords. Crystalline rocks of Precambrian age are exposed there and are commonly associated with felsenmeer. Ice caps and glaciers are common features in the highlands.

Baffin Island is deeply indented by fjords and bays. Some of the fjords are more than 150 km long. A large part of the coastline is estimated to be steep cliffs composed of bedrock. Talus appears to be a common feature along the cliffed coastline. Coarse sediments often represent talus accumulated in the beach zone or immediately offshore. A thin glacial till cover is widespread in this area. The till has very coarse texture, ranging from pebbly gravel to large boulders, and sometimes it is difficult to differentiate between till and true felsenmeer. Rock outcrops can be found on steep slopes and in places where till becomes discontinuous, and then rocks are associated with felsenmeer. Large erratics occur frequently in the area of the highlands.

In some areas hummocky and ground moraine till is thick and extensive enough and has been mapped as a single unit. End moraines and lateral morainal ridges have been mapped as single units or they are indicated by a graphic

symbol used for these features. Prominent ridges of recent lateral and terminal moraines border the existing glaciers on Baffin, Bylot and Devon Islands. Some of the glacier tongues which reach the sea or terminate in fjords may cause submarine terminal moraines. Large glaciofluvial deposits are preserved in some of the fjord heads and they have been mapped as single units. Often these deposits are subject to fluvial erosion of present streams and it is difficult to separate alluvial from glaciofluvial deposits, so they have been mapped as complex units. Marine deposits found in the Davis Highlands do not reach significant accumulations and are often omitted. Colluvial sediments in form of solifluction or talus are common in the highlands, and are associated with morainal debris and felsenmeer, and have been mapped as complex units. Often, the veneer of colluvial sediments has not been mapped.

Larger rivers and streams drain into numerous fjords and inlets. They occupy relatively wide, steep-sided valleys, forming deltas where they reach the sea. These are the only alluvial deposits extensive enough to be mapped on our scale. The alluvial deposits are often associated with glaciofluvial ones and have been mapped as complex units. Ice-contact outwash deposits, such as kames and eskers are not widespread in the highlands, and have been mapped as single units if they are large enough. Eskers are often indicated by graphic symbol.

The Davis Highland is bordered on the east by the Baffin Coastal Plain, and on the west by the Baffin Upland and Lancaster Plateau. The Baffin Coastal Plain is an area of lowlands facing Baffin Bay and extending from Henry Kater Peninsula in a northwesterly direction to Eglinton Fjord and continues as narrow strip as far north as Cape Adair. Gently undulating lowlands are composed entirely of unconsolidated Quaternary sediments of glacial and marine origin. These unconsolidated sediments are exposed to active erosion, forming low cliffs, which appear to be in rapid retreat. A result of combined frost, wave and ice action has caused an extensive slumping along these cliffs. Beach sediments vary in size from sand to coarse gravel and boulders. Sand and finer material from the cliffs have been blown and transported by prevailing winds from the N and NW and are deposited on the surface from the cliffs inland. This material is aeolian, and shows up well on aerial photographs.

A few large rivers form wide alluvial flood plains and deltas where they reach the sea. These alluvial deposits were large enough to be mapped at this scale. Lancaster Plateau dominates the northern part of Baffin Island inclu-

ding Brodeur and Borden Peninsula. Nearly horizontal Palaeozoic sedimentary rocks form a highly dissected plateau with prominent cliffs along the coast facing Admiralty Inlet. Talus accumulations are common at the base of these cliffs.

The eastern coast of Brodeur Peninsula is unbroken by fjords and inlets while larger river channels occupy broad valleys which separate the coast into units. These, sometimes nearly vertical cliffs, make an obstacle, and hence the river valleys are the only access to the plateau from the sea. The plateau surface is relatively flat on Brodeur Peninsula, dissected by a network of incised streams, giving an appearance of table-like hills. Borden Peninsula is a part of Lancaster Plateau and is characterized by a more varied topography than Brodeur Peninsula. This is due to more diverse geology in this area. Gabbro-dyke complexes cut all sedimentary rocks and influence the drainage pattern in Borden Peninsula. The intrusions of gabbro rocks, resistant to erosion, have a distinct appearance on the more eroded surface of sedimentary rocks of the surrounding terrain. Archaean crystalline rocks outcrop in the southern part of the plateau. The surface of the plateau is strewn with angular rock fragments forming felsenmeer, or it is covered with veneer of glacial drift, a result of glacial erosion.

An examination of air photographs shows thicker glacial drift accumulations with well developed ice-wedge polygons. Polygonal ground can be seen in the vicinity of Moffet Inlet and along the NE coast of Borden Peninsula at Bluff Head. Palaeozoic sedimentary rocks outcrop in spectacular cliffs along the western coast of Borden Peninsula. Cliffs are broken by large inlets and sounds such as Elwin Inlet, Bailarge Bay, Strathcona Sound and Adams Sound. Prominent cliffs along the eastern coast, facing Navy Board Inlet, are separated by broad river valleys. These rivers form wide deltas when they reach the sea and a wide intertidal zone can be seen along these deltas. Large boulders are strewn over the intertidal flats. The elevation of the plateau decreases to the SE, and also slopes less abruptly to the north. Talus slope accumulations are common along the cliffed coast of Borden Peninsula.

4.1.1.6 Bylot Island

The central part of Bylot Island is occupied by very rugged mountains composed of crystalline rocks of Precambrian age. This mountainous belt (Byam Martin Mountains), trend in a northwesterly direction across the central part of Bylot Island from Cape Graham Moor on SE to Cape Hay on NW Bylot.

The central mountainous region of Bylot Island is a part of the Davis Highlands physiographic division (Fig.4-1). 4-1). The mountainous area of Bylot Island is covered by an ice cap. Numerous glacier tongues occupy wide intermountain valleys, and some of them reach the waterline with a steep ice wall and cause calving ice bergs in the area. Some of the glaciers, believed to be in a retreating stage, are associated with large outwash plains and glacier-fed braided streams in front of the glacier tongue. The glaciers of Bylot Island are bordered by prominent lateral and often terminal moraine ridges.

Sedimentary rocks outcrop in the low terrain of NE Bylot at Cape Liverpool. Intrusions of gabbro dykes were noticed on aerial photographs in this area. Extensive glacial erosion has left a veneer of glacial drift on the rock surface which is often associated with felsenmeer, widespread in the Arctic. Relatively small areas of thicker glacial till has been mapped as single units, otherwise till was mapped as veneer over a main rock type.

Braided streams occupy former glacial valleys and glaciofluvial or alluvial sediments deposited on the valley floor are sometimes difficult to separate. Often alluvial sediments are just reworked glaciofluvial material. Alluvial fans are found along the steep valley sides. Glacial meltwater streams transport a large load of sediment from glaciers into the marine system forming distinctive plumes of suspended sediments when they enter the sea. These plumes show very well on aerial photographs. Gravel, boulder barriers are often found in front of these large deltas with a narrow river channel opening. These barriers do not permit mixing of sea and river waters and act as a natural protection for the delta environment.

River valleys and a low area of the NE tip of Bylot Island at Cape Liverpool are the only low areas in N and NE Bylot, and extensive beach deposits of boulders and coarse gravel can be found along the coastline of this part of the Island. These beaches are exposed to marine, ice and wind action. A large part of the Bylot Island coastline, facing Baffin Bay and Lancaster Sound, consists of steep, often vertical cliffs, often exceeding 500 m. Along some steep, rugged cliffs beaches do not exist and very few pocket beaches can be found at the base of some cliffs. This type of cliffed coastline is especially well exemplified west of Cape Hay. Talus formation is usually associated with steep cliffs and is relatively important because it contributes large volumes of material to the beach zone. Constant erosion of the cliffs produce regular rock fragments of variable

PHYSIOGRAPHIC DIVISIONS OF EASTERN BAFFIN AND DEVON ISLAND

(from G.S.C. published map 1254A)

Figure 4-1

size, deposited at the base of the cliffs, hence there is a constant moving of talus material to the beach zone.

Extensive areas of sedimentary rocks, outcroping in SW Bylot, are a part of the Lancaster Plateau. The rock surface is usually covered by a veneer of glacial till while ice-rich sediments show polygonal patterns in some areas. Rapid thermal degradation, erosion and slumping are fairly common along the coast. The coastline is represented by low, steep to moderate cliffs. The material in beaches is mainly sand and gravel with occasional boulders. The coast becomes higher north of Canada Point and numerous alluvial fan deposits are widespread in this area. Beach materials are very coarse, ranging from coarse gravel to large boulders. Two wide, low deltas are found in the west central part of Bylot Island facing Navy Board Inlet. These rivers are glacial-fed and transport a large sediment load, most of it deposited in the delta region and some transported and deposited into the Inlet. Low bars in the river channels and parts of the deltas not subject to floods support arctic vegetation. These deltas are subject to tides, waves and ice action.

4.1.1.7 Devon Island

Here, studies were restricted to the southeastern corner of Devon Island and the coastline of Philpots Island. Eastern Devon Island is a part of the Davis Highland physiographic division, a continuation of the mountainous region of Baffin and Bylot Island (Fig. 4-1). The Cunningham Mountains and a group of peaks west of it are formed of Precambrian crystalline rocks eroded and gullied by glacial and stream action. The rock surface is covered by felsenmeer or glacial drift, often represented by rock rubble. Most of the Davis Highlands is covered by the ice cap with several glacial tongues reaching the sea. Some of the large glacier tongues produce numerous bergs and growlers.

The southeast corner of Devon Island is a relatively flat, rubble-covered area with a very rugged shoreline. Beaches are often absent or they are short and narrow boulder and coarse gravel ridges occupy the heads of small bays and coves. Some of the beach barriers enclose small bodies of water forming numerous shallow lagoons. Boulder barriers can be found in front of the mouth of larger streams. The coast, west of this low area, is higher, having steeper slopes and more continuous beaches. Rugged cliffs of exposed crystalline rocks broken by pocket gravelly beach deposits are in contrast to the coastline previously described. Glacier tongues are bordered by conspicuous lateral morainal ridges and outwash plains exist at the sides or

immediately in front of the glacier terminus. Meltwater streams transport large amounts of suspended sediments into the sea and plumes of suspended sediment are visible on aerial photographs. Large quantities of materials eroded and transported by glacial ice, is deposited on the sea floor in front of the glacier tongues in the form of submarine moraines.

The region west of Dundas Harbour is a part of the Lancaster Plateau. The plateau is formed of flat, or nearly flat-lying sedimentary rocks, dissected by stream erosion into table-like hills, as are typical features for the Lancaster Plateau. Crystalline rocks of Precambrian age underlie the sedimentary strata and outcrop at the base of the cliffs east of Croker Bay.

Two large, calving glacier tongues terminate in the head of Croker Bay, sending bergs into the Bay. Cliffs along the coast of Croker Bay are associated with the talus deposits which supply beaches with coarse material. Low areas on both sides at the entrance of Croker Bay show a number of well-preserved raised beach deposits, with numerous ponds in the low area between raised beaches. The beach materials range in size from coarse gravel to boulders.

Philpots Island is an extensive lowland and its rubble or boulder-covered surface has a very unusual appearance. Boulders are strewn everywhere in this low area. The coastline of Philpots Island is low, rocky and rugged and beaches, if present, are short ridges of unusually large-size boulders. Numerous lagoons are enclosed by these rocky ridges. The Island is connected to Devon Island by a narrow isthmus and the area is a low marine plain with large boulders strewn on its surface. Numerous, shallow lakes and ponds give the area a kettled appearance and beaches are lacking in this area. A few short offshore barriers, formed of boulders, are recognized in the waters of Bethune Inlet.

A prominent lateral morainal ridge borders the western coast of Bethune Inlet. Material of different sizes, ranging from silt to coarse gravel and boulders, form this lateral moraine. Meltwater streams cross large outwash deposits and introduce a large amount of silt into the waters of Bethune Inlet. Devon Island glaciers descend to the coast in this area. They have smooth, rounded surfaces and produce a large number of bergs and growlers into Baffin Bay.

4.1.2 Atmospheric Studies

Petro-Canada, in conjunction with the Atmospheric Environment Service, at Downsview, Ontario, have detailed climatological studies for the region of Baffin Bay presently under way. These studies are not concluded as yet and are, therefore, not included in the Initial Evaluation herein.

Studies on specific meteorological aspects relevant to the drilling sites are in preparation at this writing. Both the climatological and the more detailed meteorological studies will be submitted to regulatory agencies in future environmental statements.

4.1.3 Ice Studies

4.1.3.1 Introduction

Ice has been the major physical obstacle in man's efforts to inhabit, explore and exploit the Arctic regions. As a result, self interest and curiosity have combined to motivate the accumulation of a centuries-old record of observations on ice thickness, location, extent, etc. As in the case of other environmental parameters, the most useful and comprehensive ice data have been obtained only recently, utilizing the higher accuracies and coverage associated with modern scientific observational techniques.

The general intent of this report is to provide an introduction to the sea ice portion of a forthcoming Environmental Impact Statement. It begins with a historical summary of the major steps in the development of man's knowledge of the ice of Baffin Bay and Lancaster Sound. This is followed by a brief description of the state of this knowledge in the early 1950's, our previously chosen cutoff date for this interim document. Some more recent data are also included in this summary in order to clarify some aspects of ice cover behaviour. A closing chapter is devoted to a listing of major post-1950 developments including an outline of the 1978-79 Petro-Canada sea ice programs.

4.1.3.2 History

The earliest written accounts of man's contact with sea ice arose out of the epic sea voyages which originated from the Norse settlements of Greenland and Iceland as well as from the British Isles (Mowat, 1960). The most significant explorations took place around 1000 A.D. led by Erik the Red, Bjarni Herjolfsson and Thorfinn Karlsefni. These parties covered much of Baffin Bay and its western shores and south as far as Newfoundland. Their success was in no small

part aided by their timing at the peak of the so-called "Little Climatic Optimum" which reportedly cleared the ice from Baffin Bay and, more arguably, from part of the Arctic Ocean.

Conditions more suitable for ice studies, if not for sea travel, attended upon the next major period of exploration running from approximately 1500 to 1800 A.D. This era overlapped the "Little Ice Age" (1650-1850) in which a general cooling of the northern hemisphere was noted. The resulting worsened ice conditions were perhaps partially responsible for the later decline in exploration activity from the levels of the later 16th and early 17th centuries when Frobisher, Davis, Hudson and Bylot all led major expeditions. The motivation for driving forces in these later explorations was the need for a short route to Asia and the desire to expand the Hudson Bay fur trade. As a result, ice observations still tended to be practical evolving sailing routes, for example, which took advantage of the characteristic low early-summer ice densities of the southwest Greenland coast and avoided the congested regions just east of Baffin Island. Occasional major contributions were made such as Robert Bylot's discovery, in 1616, of a vast area of open-water and thin ice, the "North Water", at the northern end of Baffin Bay.

Nevertheless, a systematic approach to the ice properties of Baffin Bay and its western approaches was not really forthcoming until the end of the Napoleonic Wars, in 1818, initiated the "modern" era of exploration. Again in the earlier part of this period, major efforts were devoted to geographical exploration, primarily of the maze of channels interior to the Canadian Arctic Archipelago. Lancaster Sound, after its re-discovery by Ross in 1818 and explorations by Parry in 1819-20, soon was realized to be the likely eastern entrance of the Northwest Passage. From the tribulations of the various expeditions, the very broad outlines of ice properties and movements within the Archipelago began to emerge. Distinctions were drawn between those bodies such as McClintock Channel which tended to fill with massive jumbles of thick multi-year ice and those such as Lancaster Sound where lengthy summer ice-free conditions usually obtained. Characteristic break-up and freeze-up dates were gradually accumulated in ship-logs and expedition journals. Of particular use have been the logs of ice-beset ships and, in one case, the journal kept by a stranded party from the "Polaris" which survived an epic icefloe drift of nearly 1000 km. For many years, the positions reported in these drifts provided the only information available on the directions and magnitudes of the ice flow.

cation allows adequate detailed or generalized descriptions of different morphologic units mapped on this scale. A primary subdivision was made by grouping related sediments into generic categories. The generic categories used are: alluvial (active and inactive), colluvial, deltaic, glaciofluvial, ice-contact outwash, marine, morainal and bedrock. Generic categories are indicated by an upper case letter beginning each word. The secondary subdivision was based on the morphology of each terrain unit. The morphologic modifiers used are: plain, rolling terrain, hummocky, ridged, terraced, kettled, fan, veneer, channeled and raised beaches. Morphologic modifiers are placed behind genetic categories, and are presented by a low cased letter beginning each word.

Extensive areas of exposed bedrock of sedimentary origin, crystalline - granitoid and gneissic rocks, volcanics and numerous gabbro dykes are found throughout the studied area. Because of the diversity of exposed bedrock, lithologic modifiers were introduced in the legend of the maps in preparation. Lithologic modifiers used are: carbonate, granite, gneiss, shale, quartzite, sandstone, siltstone and volcanic. Lithologic modifiers are identified on the maps by a low case letter placed in the upper left corner of the letter "R" indicating bedrock.

In the map series in preparation for the Atlas, terrain units used are either single units or complex units of two or more single deposits. The single deposits are identified on the maps by a label consisting of a lower case letter indicating texture; upper case letter indicating genetic category, followed by a lower case letter indicating morphologic category.

> Example: g,sAt - gravel and sand in an alluvial terrace. Complex units are identified by combination of two or more single units. A horizontal line between units indicates veneer of unconsolidated deposits (3-10 ft. thick) over the main terrain type. A vertical and a dash line identify the percentage of single units in a complex terrain form.

4.1.1.4 Shoreline Classification

The shoreline classification of the G.S.C. Coastal Research Group was adopted for this project. In general, two types of coastal zones have been identified by this classification: one constructed in bedrock and one constructed in unconsolidated deposits. The slope of immediate backshore areas was defined as steep, moderate and low.

effect on the melting of the characteristic shallow-draft flow ice.

Perhaps the most significant event in advancing our knowledge of sea-ice and icebergs occurred in 1912 when the sinking of the "Titanic" in a Grand Banks ship-iceberg collision mobilized the sea-faring nations of the world to organize the International Ice Patrol (IIP) under the administration of the U.S. Coast Guard. This organization had as one of its tasks the gathering of sea ice and iceberg observation data. By evaluating and correlating ship reports with the observations made by its own vessels the IIP began to put iceberg studies on a quantitative basis. Initially, of course, its efforts were directed toward locating and enumerating iceberg concentrations, drift rates, etc. in order to provide the IIP Grand Banks and North Atlantic shipping lane advisories. This responsibility eventually led to the development of the Coast Guard's present on-going program of oceanographic, meteorological and other environmental measurements. Data-taking, initially, was carried out by cutters on surveillance duty. Later, specific expeditions were mounted on board the cutters "Marion" and "General Greene" to obtain the data eventually used to derive much of our modern understanding of southern Baffin Bay, Davis Strait and more southern waters. A major summation of the resulting sea ice and iceberg results was provided by Smith (1931). This classic work put the monthly iceberg censuses on a more accurate footing, provided detailed experimental data on the properties of sea ice and icebergs, and in general set up the groundwork for an iceberg condition forecast system based on an oceanographic and meteorological monitoring program. A program of regular iceberg-census cruises in Baffin Bay and Davis Strait was begun in 1940 by the USCGC "Northland". However, the intervention of war prevented its continuation as a regular part of IIP activities until 1946 when PBY-5A Catalina aircraft were used to extend the frequency and extent of coverage. By 1949, ice reconnaissance was solely the responsibility of the Coast Guard aircraft, freeing surface vessels for oceanographic and rescue duties.

Major improvements in sea ice as opposed to iceberg data gathering appeared shortly after the 1950 cut off date of our historical summary.

The most important of these was the initiation of long-range aircraft ice surveys of Baffin Bay and the eastern Arctic Archipelago by the U.S. Navy Hydrographic Office. In this program, trained ice observers recorded, weather permitting, local ice concentrations, type-distributions, ridging densities as well as specific navigational information such

symbol used for these features. Prominent ridges of recent lateral and terminal moraines border the existing glaciers on Baffin, Bylot and Devon Islands. Some of the glacier tongues which reach the sea or terminate in fjords may cause submarine terminal moraines. Large glaciofluvial deposits are preserved in some of the fjord heads and they have been mapped as single units. Often these deposits are subject to fluvial erosion of present streams and it is difficult to separate alluvial from glaciofluvial deposits, so they have been mapped as complex units. Marine deposits found in the Davis Highlands do not reach significant accumulations and are often omitted. Colluvial sediments in form of solifluction or talus are common in the highlands, and are associated with morainal debris and felsenmeer, and have been mapped as complex units. Often, the veneer of colluvial sediments has not been mapped.

Larger rivers and streams drain into numerous fjords and inlets. They occupy relatively wide, steep-sided valleys, forming deltas where they reach the sea. These are the only alluvial deposits extensive enough to be mapped on our scale. The alluvial deposits are often associated with glaciofluvial ones and have been mapped as complex units. Ice-contact outwash deposits, such as kames and eskers are not widespread in the highlands, and have been mapped as single units if they are large enough. Eskers are often indicated by graphic symbol.

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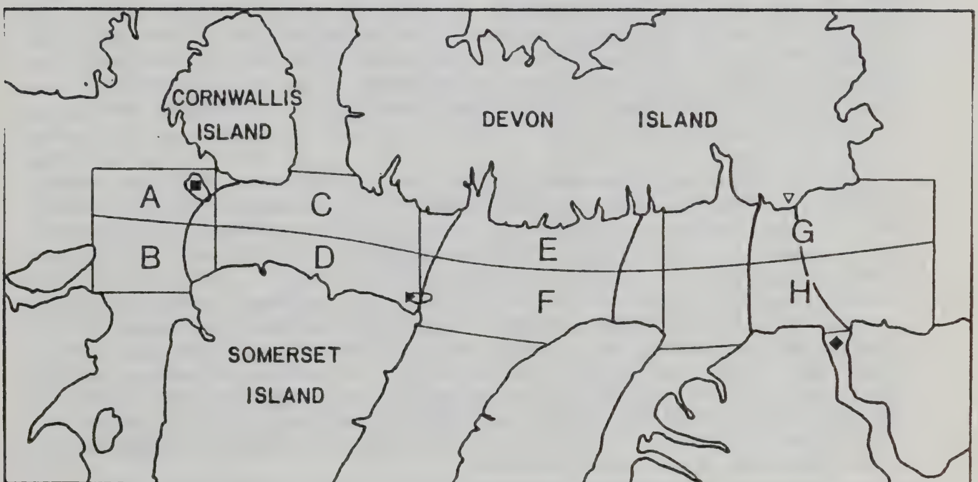

■ Griffith Island
▶ Prince Leopold Island
▽ Cape Warrender
◆ Navy Board Inlet

Figure 4-2. Delineation of zones for ice velocity averaging. This Figure also contains the lines along which stable landfast ice edge formation has been observed.

The central mountainous region of Bylot Island is a part of the Davis Highlands physiographic division (Fig.4-1). 4-1). The mountainous area of Bylot Island is covered by an ice cap. Numerous glacier tongues occupy wide intermountain valleys, and some of them reach the waterline with a steep ice wall and cause calving ice bergs in the area. Some of the glaciers, believed to be in a retreating stage, are associated with large outwash plains and glacier-fed braided streams in front of the glacier tongue. The glaciers of Bylot Island are bordered by prominent lateral and often terminal moraine ridges.

Sedimentary rocks outcrop in the low terrain of NE Bylot at Cape Liverpool. Intrusions of gabbro dykes were noticed on aerial photographs in this area. Extensive glacial erosion has left a veneer of glacial drift on the rock surface which is often associated with felsenmeer, widespread in the Arctic. Relatively small areas of thicker glacial till has been mapped as single units, otherwise till was mapped as veneer over a main rock type.

Braided streams occupy former glacial valleys and glaciofluvial or alluvial sediments deposited on the valley floor are sometimes difficult to separate. Often alluvial sediments are just reworked glaciofluvial material. Alluvial fans are found along the steep valley sides. Glacial meltwater streams transport a large load of sediment from glaciers into the marine system forming distinctive plumes of suspended sediments when they enter the sea. These plumes show very well on aerial photographs. Gravel, boulder barriers are often found in front of these large deltas with a narrow river channel opening. These barriers do not permit mixing of sea and river waters and act as a natural protection for the delta environment.

River valleys and a low area of the NE tip of Bylot Island at Cape Liverpool are the only low areas in N and NE Bylot, and extensive beach deposits of boulders and coarse gravel can be found along the coastline of this part of the Island. These beaches are exposed to marine, ice and wind action. A large part of the Bylot Island coastline, facing Baffin Bay and Lancaster Sound, consists of steep, often vertical cliffs, often exceeding 500 m. Along some steep, rugged cliffs beaches do not exist and very few pocket beaches can be found at the base of some cliffs. This type of cliffed coastline is especially well exemplified west of Cape Hay. Talus formation is usually associated with steep cliffs and is relatively important because it contributes large volumes of material to the beach zone. Constant erosion of the cliffs produce regular rock fragments of variable

the recovery of Petro-Canada moored current meters, presently in place in Lancaster Sound and Baffin Bay.

Assessments of typical heavy and light summer ice conditions (for September 1-15) are shown in Figures 7 and 8, respectively in the Pilot of Arctic Canada (1970) (p. 141 and 142). These figures highlight the likelihood of light sea ice conditions in all except the most northern sectors of the Petro-Canada lease area. Nevertheless, the simplifications necessary in such a chart hide local peculiarities of the ice distribution and flow. Of particular note are the streams of ice which flow into Lancaster Sound by moving southward, then southwestward along the eastern Devon Island coast and by the easterly flow which follows the southern edge of Parry Channel east of Prince Regent Inlet. A September 17, 1977 Landsat image (Figure 4-3) of the former stream indicates a typical extent and a width which can range up to several kilometres. Such features contain icebergs as well as the full range of sea ice floe-sizes. Thus, although they occupy considerably less than one-tenth of the pictured sea surface, they represent a considerable hazard to immobile drillships operating in these waters. Much of the ice in this stream shown eventually joins the southern border stream and exits again into Baffin Bay in accord with the surface current flow patterns outlined in Section 4.1.7. However, considerable concentrations of ice can accumulate in slowly-moving eddy-like structures in mid-Channel both immediately to the east and immediately to the west of the region of strong southerly flow north of Navy Board Inlet (see Section 4.1.7). The ice in such structures (see Figure 4-4 for example) can be driven into exploration areas by appropriate combinations of wind and current forcing.

A typical annual progression of ice clearing in Baffin Bay is illustrated in Figures 4-5 to 4-14. Particular features worth noting are the very early clearing of the west Greenland coast and the tendency for ice to linger in the vicinity of Melville Bay and along the eastern Baffin Island coast. The Cape Dyer region, shown still occupied by ice in Figure 4-10, is traditionally the last portion of the Baffin Island coast to achieve clearing. Some measures of the yearly variation in the southerly ice retreat at the latitude of Lancaster Sound can be obtained from Figure 4-11 in which the approximate mid-July pack boundaries are plotted for the years 1953-1955.

The freeze-up sequence, reasonably enough, proceeds from the western side of Baffin Bay and is illustrated in Figures 4-12 to 4-14.

size, deposited at the base of the cliffs, hence there is a constant moving of talus material to the beach zone.

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Figure 4-4: A June 9, 1973 Landsat image of central Lancaster Sound. The southern coast of Devon Island is visible to a point east of Cape Warrender.

4.1.2 Atmospheric Studies

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4.1.3 Ice Studies

4.1.3.1 Introduction

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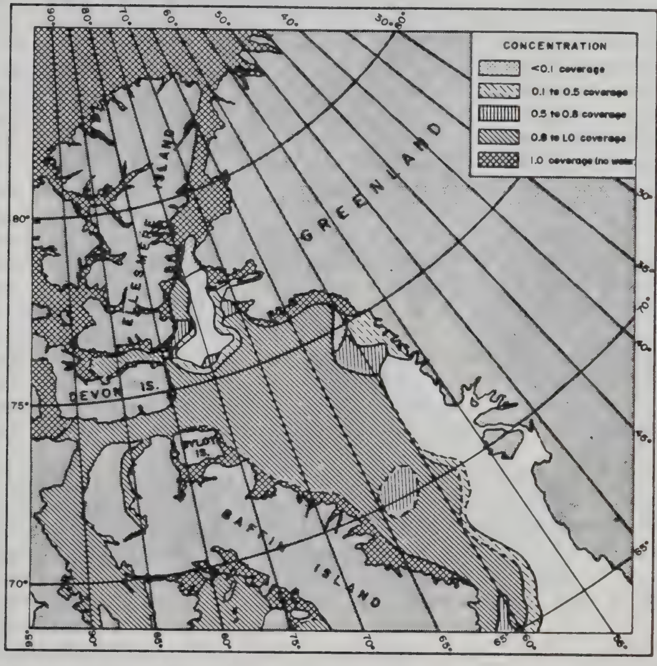


Figure 4-6: Ice conditions in Baffin Bay and the Arctic archipelago, June 1 - 6, 1955.

Nevertheless, it was difficult to derive a detailed, even descriptive understanding of the spatially and time-varying ice packs simply on the basis of the observations of men often functioning at the very edge of survival. The necessary foundation for such understanding began to be established in the latter quarter of the 19th century when major scientific expeditions were sent forth by Denmark, Sweden and the United States. Of these, the Swedish "Sofia" expedition of 1883 (Hamburg, 1884) and the Danish "Fylla" voyages of 1884, 1886 and 1887 (Wandel, 1891) were most notable in that they established some major elements of the oceanography of Baffin Bay, Davis Strait and the southern approaches to Greenland. The description and identification of the source of the West Greenland current and the southward surface flow along the Baffin Island coast were essential first steps in deducing the pattern of ice movement in Baffin Bay. Similarly, data from the Danish "Ingolf" expeditions in 1895 and 1896 revealed the low temperature of the Lancaster Sea relative to the waters to its east. This fact was essential in the understanding of iceberg survival rates at sub-Arctic latitudes. The iceberg drift problem was for the first time, put on a reasonably quantitative basis by Mecking (1907) using data gathered by the increasing number of ships travelling in northern waters. The resulting record of iceberg counts for the period 1880-1899 was later shown (Smith, 1931) to have greatly overestimated the iceberg numbers in all areas due to Mecking's failure to account for multiple sightings of each iceberg. Nevertheless, for the first time it offered a reliable upper limit (several thousand) on the number of icebergs which appear south of 48°N latitude.

The growing interest in icebergs also resulted in the first attempt by Steenstrup (1893) to relate the under-and-above water berg dimensions. His results indicated (maximum) height to (maximum) draft ratios ranging from 1:7.4 to 1:8.2 or approximately equal to that expected of the freeboard and submerged ice masses. Other measurements by Rodman (1890), Krummel (1907) and Dawson (1907) indicated a slightly larger (1:5 - 1:6) median ratio and found unambiguous evidence for the occurrance of large, approximately 1:1, ratios.

The field work of the early twentieth century tended to build up the record of sea ice observations and fill in major gaps in the oceanographic picture. Following the Danish "Tjalfe" expedition in West Greenland in 1908, Nielsen (1909) (1928) deduced major features of the east and southern Baffin circulation including the fact that, since the surface layer temperatures of Davis Strait remain negative throughout the year, the underlying warm Atlantic water has no direct

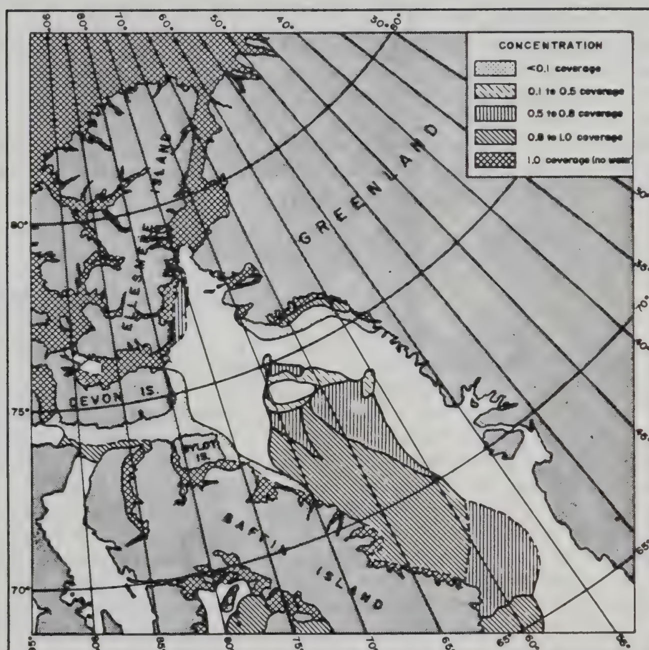


Figure 4-8: Ice conditions in Baffin Bay and the Arctic archipelago, July 1 - 6, 1955.

as the presence of leads, polynyas, etc. An accompanying program set up a network of land-based stations from which air-temperature and pressure, local ice-thickness and ice-condition information and other data could be fed into the Oceanographic Forecasting Central Division of the Hydrographic Office. Oceanographic data were gathered from U.S. Navy and Coast Guard vessels whose responsibilities included the occupation of selected oceanographic stations throughout the Baffin Bay region. Utilizing prepared "synoptic" ice charts, derived surface-current and temperature data, extrapolated maritime degree-day accumulations, prognostic mean air pressure charts and other information, the Hydrographic Office issued 48-hour, 5-hour and 30 day (outlook) predictive advisories. These duties in the eastern Arctic were later gradually taken over by the Canadian Atmospheric Environment Service. The combined U.S.-Canadian record of detailed ice conditions thus extends backward, almost continuously, to 1951.

4.1.3.3 The Ice Environment

4.1.3.3.1 Ice Cover Characteristics

The typical mid-winter (February) distribution of ice in the eastern Arctic is shown in Figure 6 (p. 139) in the Pilot of Arctic Canada (1970). This sketch indicates the well known areas of anomalously low ice concentration in Smith Sound (the "North Water") and south of Disco Island. It indicates however, that most of the Baffin Bay-Davis Strait region is covered by a mass of mainly first-year ice of average 1-2 metres thickness. This ice undergoes intermittent, restricted motion. A quantitative picture of this motion has been developed only in recent years through the use of devices, observational satellites and satellite-relayed drift buoy transmissions, which were unavailable in the pre-1950 period considered in this report. The details of this winter motion are relevant to summer exploration activities largely through their relationship with the timing and nature of the spring-summer break-up process in areas such as the eastern Parry Channel. In the latter region, as indicated in the Figure noted above, rather distinct and long lived boundaries tend to form between the landfast ice on one hand and the moving ice on the other. However, the positions of these boundaries, which occur at the longitude of Prince Leopold Island and in Prince Regent Inlet, vary widely from year to year. Thus, although the Prince Leopold Island position shown represents the most common western boundary of the moving winter ice zone, a number of other positions have been occupied in the years since 1951. These alternative locations are illustrated in Figure 4-2 (Marko, 1978). Thus, for

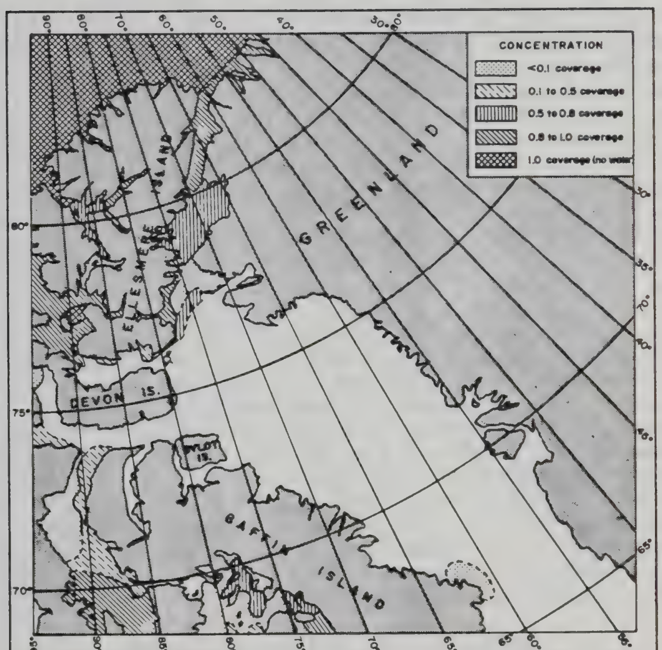


Figure 4-10: Ice conditions in Baffin Bay and the Arctic Archipelago, September 1 - 6, 1955.

example, in the first field season (1978) of the Petro-Canada environmental program, ice edge formation occurred along the Navy Board Inlet - Cape Warrender line, the most eastward of the possible sketched in Figure 4-2.

Two circumstances of this situation are worthy of note: 1) the timing (usually mid-July) of the disintegration of the landfast ice edge is relatively independent of ice edge locations; and 2) the moving ice tends to clear to the east of the landfast ice edge in the month of May. As a result, year to year changes in the landfast ice edge position introduce great variability in both the summer radiative heating of the Lancaster Sound surface water and in the amount of ice which must flow out of the eastern end of the Sound in late summer. Thus, when ice edge formations occur along a western line, i.e. at the longitudes of Prince Leopold Island or Griffith Island, Lancaster Sound and perhaps most of Barrow Strait remain nearly ice-free from early June until perhaps late July and early August when the deteriorating ice edge releases the ice packs of Viscount Melville Sound, Wellington and Prince Regent Channels, McDougall Sound and the northern Archipelago for flow through Lancaster Sound into Baffin Bay. However, this ice deteriorates quickly in the previously solar-heated waters of the Sound, resulting in relatively little sea-ice outflow to Baffin Bay. In the alternative case, however, an eastern ice edge position allows little heating of the surface waters of Lancaster Sound because of the high reflectivity and insulating properties of the landfast ice cover. As a result, when the summer break-up occurs an additional amount of ice equivalent to perhaps the entire coverage of Lancaster Sound and Barrow Strait exits into Baffin Bay. Furthermore, the degree of melting and deterioration experienced by this ice will be significantly lessened by the lower temperatures of the previously ice-covered waters.

There is some evidence (Marko, 1977) that the cited critical variations in winter landfast ice edge position are associated with the east-west surface wind components which obtain over the winter months. This possibility may also be reflected in the correlation of average winter velocities in the moving ice zone (see Section 4.1.3.3.3) with the longitudinal position of the landfast ice boundary. In sum, the 1975-76 and 1976-77 winter data (Marko, 1978) suggest that rapid winter ice flow tends to shift this boundary westward. Comparison of historical ice-edge positions and geostrophic wind estimates are needed to explore this possibility further. The role of near surface currents in winter movement and ice edge stabilization may also now be examined pending

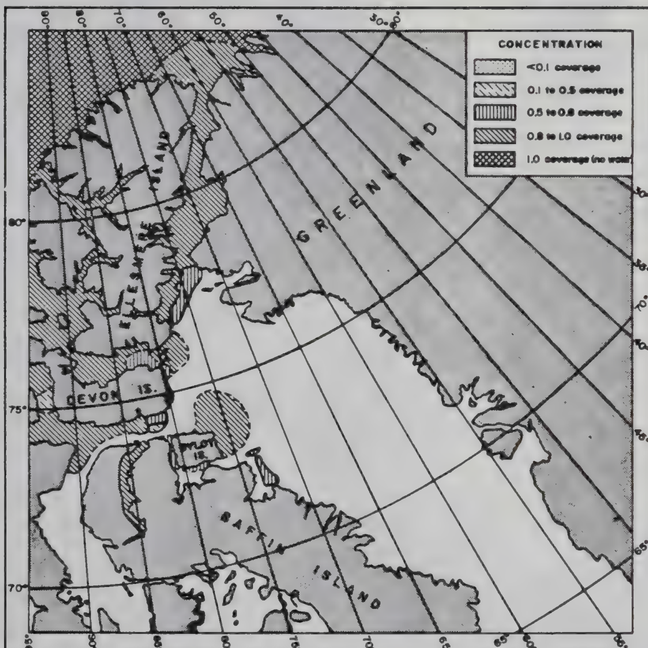


Figure 4-12: Ice conditions in Baffin Bay and the Arctic Archipelago, October 7 - 12, 1955.

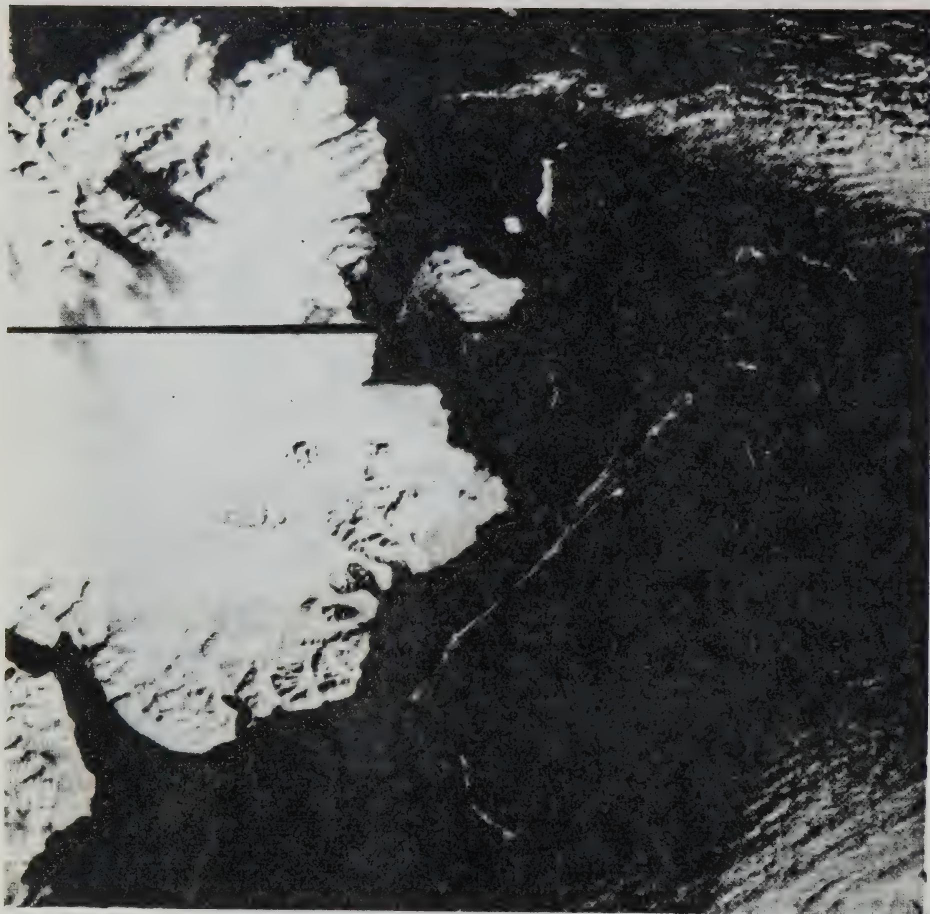


Figure 4-3: A September 17, 1977 Landsat image of an ice stream off south-western Devon Island.

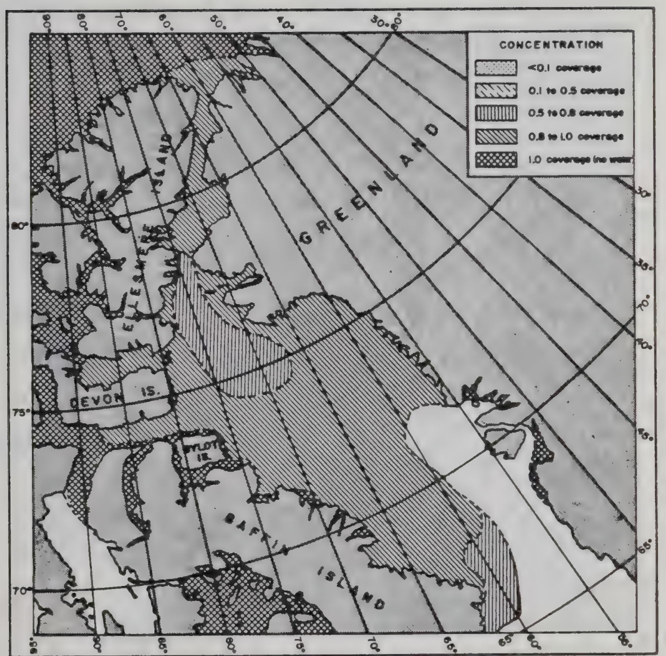


Figure 4-14: Ice conditions in Baffin Bay and the Arctic Archipelago, November 25 - 30, 1955.

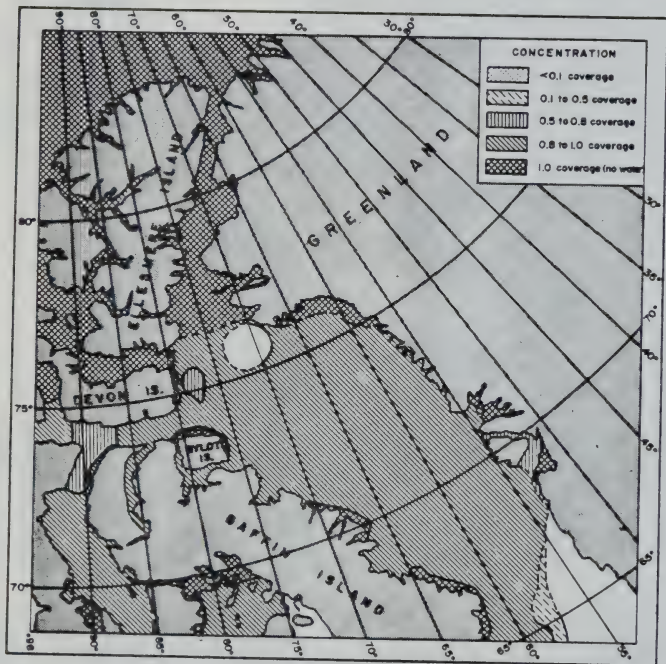


Figure 4-5: Ice conditions in Baffin Bay and the Arctic archipelago, April 19-24, 1955.

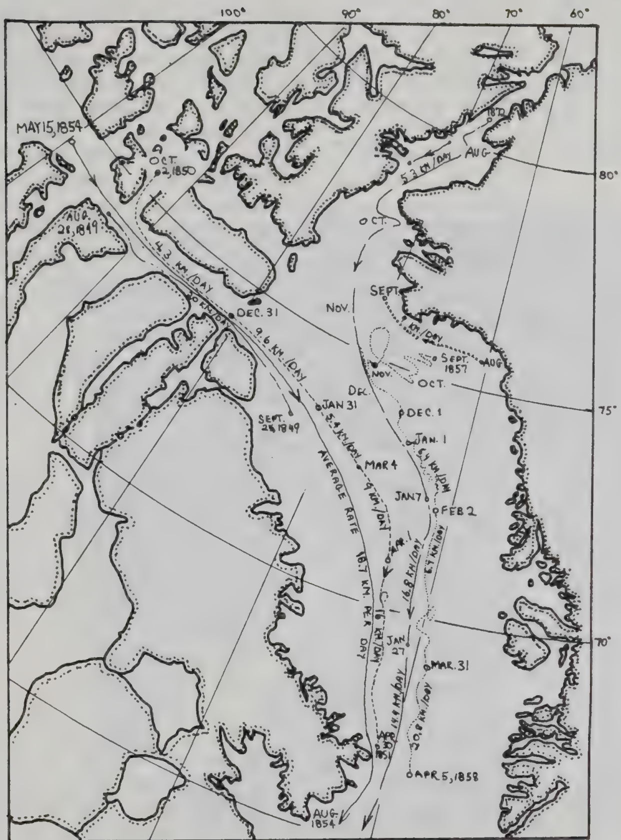


Figure 4-15: Tracks of several ice beset vessels and the Polaris floe party (Smith, 1931). Average net speeds are given for major segments of each track.

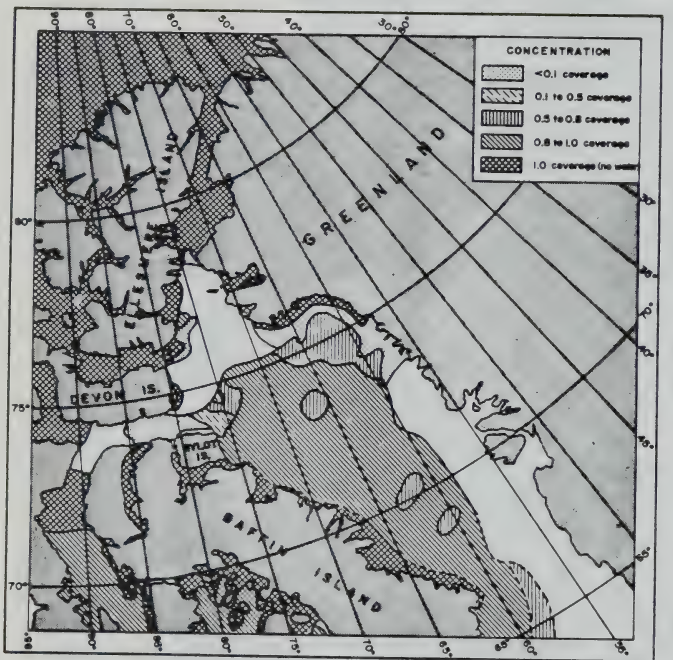


Figure 4-7: Ice conditions in Baffin Bay and the Arctic archipelago, June 13 - 18, 1955.

ted from the satellite imagery of the 1973-77 period. These average vectors clearly show the tendency for strongly eastward or east-southeastward flow on the south side of Lancaster Sound. The average summer value of 10-15 km/day in zones D, F and H are less than the typical ice flow rates in the coastal streams as a result of the inclusion of data from the region of the Channel axis where slower more meandering flows obtain. Drift buoy data (Fissel, and Marko (1978) and Fissel, Lemon and Wilton (1978)) indicate that movements of 50 km/day are not uncommon in the coastal flow.

The pronounced southwestward set and rapidity of ice movements in zone G in northeastern Lancaster Sound is evident in the summer data of Figure 4-16. Similarly, the low values of the average velocities in the northern zones C and E west of the 85° line of west longitude reflect the irregular nature of the flow in these areas and do not support the existence of a northern coastal current comparable in magnitude and unidirectionality to the southern current.

The averaged ice vector data indicate that the greater speed of flow in the southern half of the Channel is maintained during the winter period. As indicated in Section 4.1.3.3.1, considerable year to year variations in the average winter ice-movement magnitudes occur which may influence the equilibrium position of the winter landfast ice edge. The 1975-76 and 1976-77 monthly average east-west speeds are plotted in Figure 4-17 to illustrate this aspect of variability.

4.1.3.3.4 Icebergs

The International Ice Patrol estimates that 85% of the icebergs which reach the Grand Banks of Newfoundland originate from the tidewater glaciers of west Greenland. The estimated annual output of these glaciers is 10,000 to 15,000 icebergs arising chiefly from the 20 major glaciers mapped in Figure 4-18. Other sources of bergs and their percentages are: East Greenland (10%), and the glaciers and iceshelves of Ellesmere, Devon and Bylot Islands (5%). Few bergs of east Greenland origin manage to enter, following the West Greenland current, into the Lancaster Sound-Northwest Baffin Bay region. Instead, the most likely source of bergs encountered in the latter area is Melville Bay into which 19 glaciers annually calve some 1500 icebergs. Additionally, bergs produced in more southern areas of the west Greenland coast are transported into Melville Bay region by the northerly component of the West Greenland Current. The presence of numerous banks and shoals in this Bay leads to the grounding of many bergs. As a result, Melville Bay acts as a

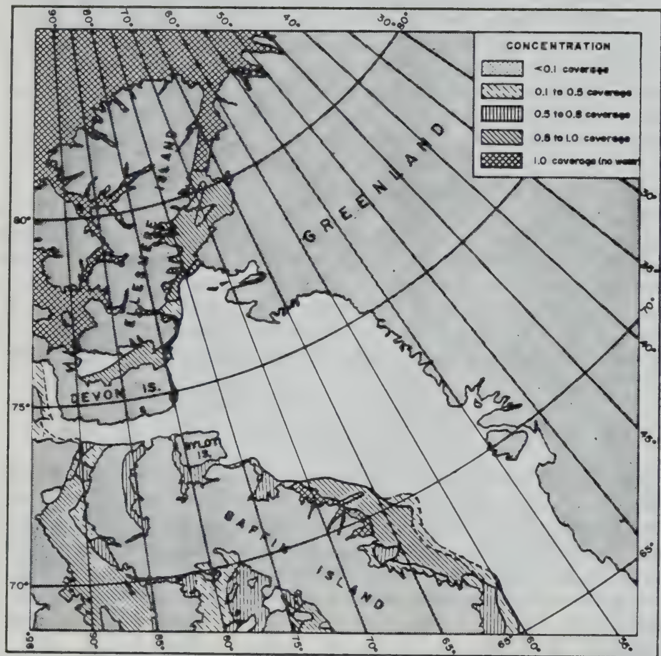


Figure 4-9: Ice conditions in Baffin Bay and the Arctic Archipelago, August 1 - 6, 1955.

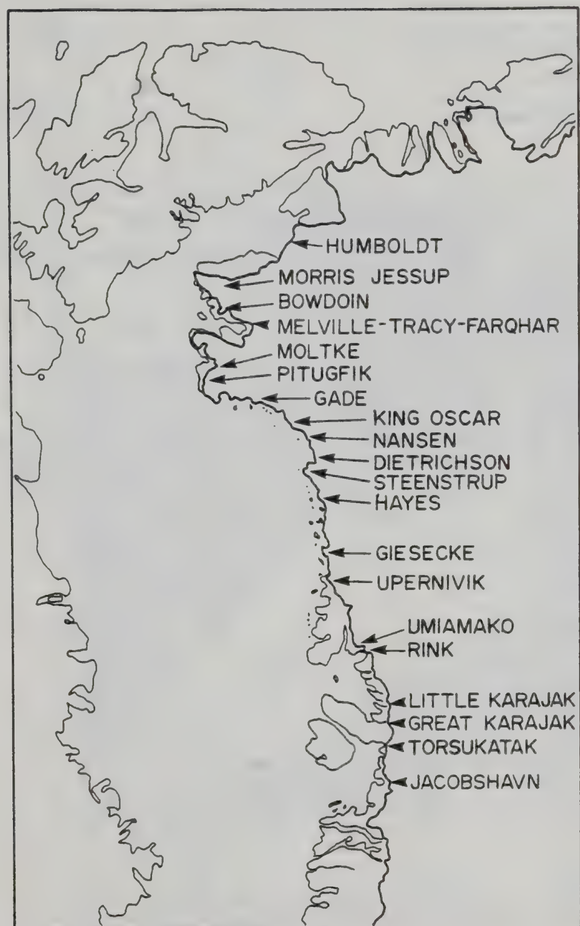


Figure 4-18: The major iceberg-producing glaciers of West Greenland.

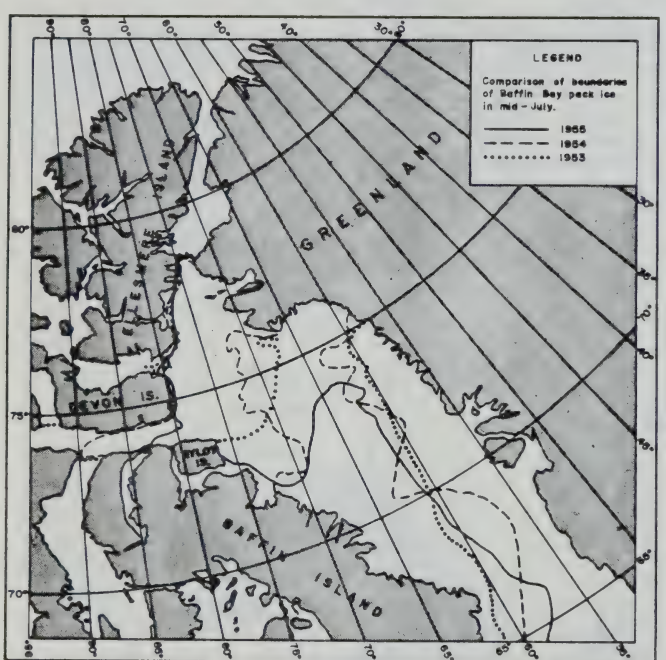


Figure 4-11: Approximate mid-July ice pack boundaries in Baffin Bay for the years 1953-1955.

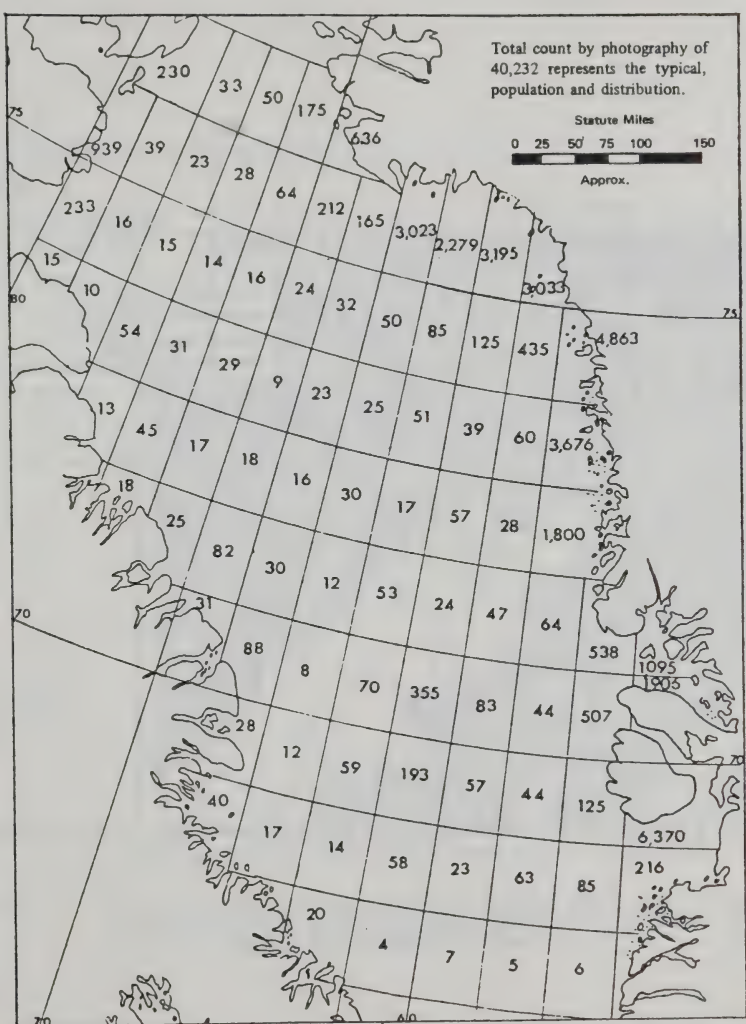


Figure 4-19: The August 1949 iceberg counts in Baffin Bay and adjacent waterways. Heavy berg concentrations are seen to be confined to coastal areas particularly in Melville Bay and along the western shore of Baffin Bay.

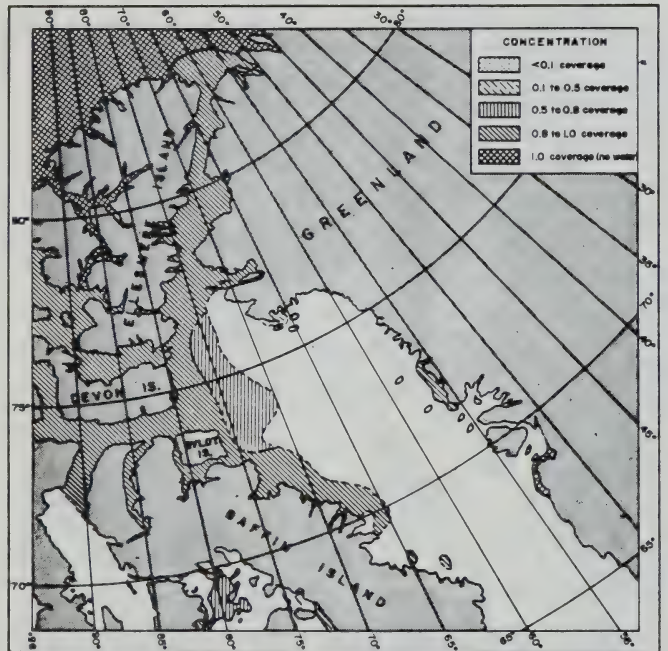


Figure 4-13: Ice conditions in Baffin Bay and the Arctic Archipelago, October 25 - 31, 1955.

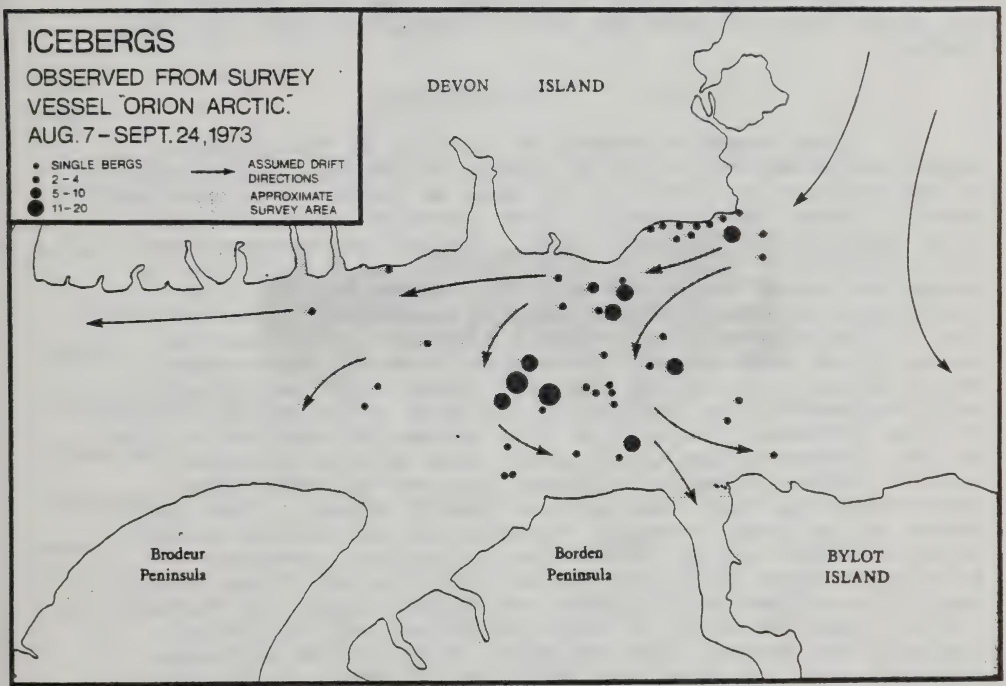


Figure 4-21: The distribution of iceberg sightings in eastern Lancaster Sound according to the 1973 summer cruise of the M.V. Orion Arctic (Milne and Smiley, 1978).

4.1.3.3.2 Ice Characteristics

The ice covers of Lancaster Sound and Baffin Bay undergo essentially complete annual replacement. The resulting predominant first year ice is limited to roughly 2 meters growth in thickness. This ice is locally thickened by almost ubiquitous rafting, ridging and hummocking processes. Smith (1931) has noted the presence of a large amount of ice up to 4 meters in thickness in a 36 mile wide park off Cape Dyer. Up to 5 meter thick multi-year floes also appear in all areas, arising from the Arctic Archipelago and the Arctic Ocean.

4.1.3.3.3 Ice Movements

The summer movements of sea ice in the Lancaster Sound-Baffin Bay region by and large follow the trajectories of the dominant currents in the area as indicated in standard charts. Thus, ice generally flows southward along the western side of northern Baffin Bay, turning southwestward off the southeastern corner of Devon Island, until it moves across Lancaster Sound south of Cape Warrender. It then turns eastward again before reaching Navy Board Inlet joining, in the process, the eastward flowing current and ice stream which moves along the southern edge of the eastern Parry Channel. Satellite imagery (Marko, 1978) and preliminary drogued-drifter results of the 1978 Petro-Canada field program indicate that most of this stream follows the outline of the northern Bylot Island coast west of Cape Liverpool. However, there is ample evidence that ice can enter into eddy-like flows near Cape Hay and Cape Liverpool. The latter appear to be quasi-permanent features of the surface current north of Bylot Island. Historical tracks of ice-beset vessels (see Figure 4-15) and recent satellite-monitored drogued buoys (Fissel and Marko (1978) and Fissel, Lemon and Wilton (1978)) indicate that, if these anomalous eddy regions are ignored, the coastal flow off north Bylot Island continues eastward until at least the 76°W line of longitude at which point it can turn southward and follow closely the Baffin Island coastline. Alternatively, it may continue on a general east-southeastward set carrying it into the middle of Baffin Bay where it moves southward, tending to pass through the western half of Davis Strait. The average daily velocities along portions of the tracks indicated in Figure 4-15 suggest the rates of flow and its seasonal and year to year variability. A more up to date compilation of ice movements in the Barrow Strait-Lancaster Sound area is indicated in Figure 4-16 (Marko, 1978) in terms of regionally averaged (according to the delineations of Figure 4-2) ice vectors obtained from summer and winter ice displacement data extrac-

Table 4-1.

Height to draft ratios as a function of iceberg shape classification.

Class	No. of Bergs Measured	Average Height to Draft Ratio (1:)	Standard Deviation
tabular	7	4.46	2.47
broken tabular	9	4.26	1.48
pinnacle	4	2.31	.32
drydocked	3	2.41	1.16
domed	7	6.30	2.76

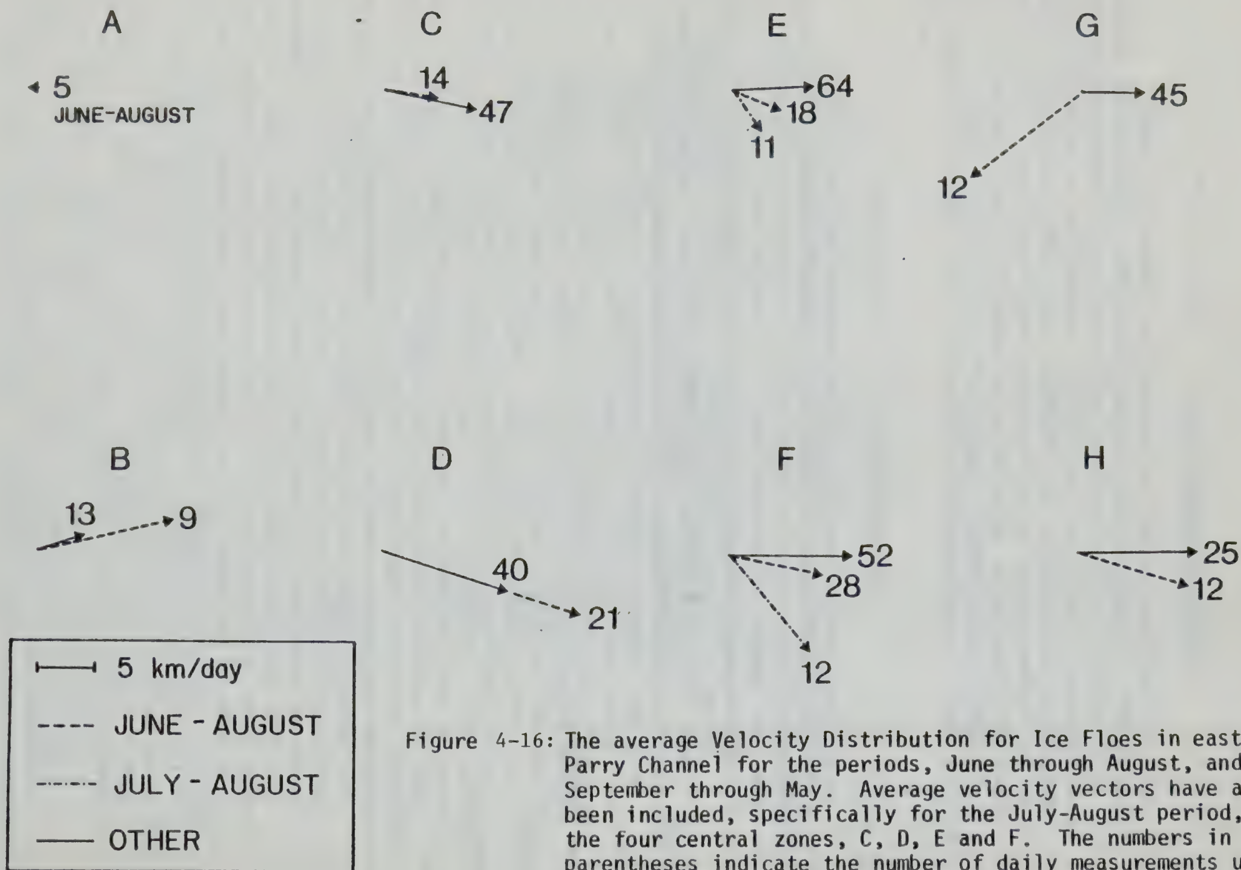


Figure 4-16: The average Velocity Distribution for Ice Floes in eastern Parry Channel for the periods, June through August, and September through May. Average velocity vectors have also been included, specifically for the July-August period, in the four central zones, C, D, E and F. The numbers in parentheses indicate the number of daily measurements used in each average velocity computation.

cover behaviour such as lead-formation and stability still remain outside current rheological theories.

The 1978 Petro-Canada field studies directly followed several other programs carried out for Norlands Petroleum Ltd. by various government and private sector organizations. The sea ice-component of these programs largely consisted of the previously cited satellite observations of the eastern Parry Channel (Marko, 1978), sea ice density assessments (Markham, 1976) and iceberg censuses such as that performed on the 1973 cruise of m.v. "Orion Arctic" (FENCO, 1974).

The Petro-Canada program was directed toward:

1) defining more clearly the extent to which sea ice and icebergs pose a hazard to proposed operations in eastern Lancaster Sound and the adjoining segments of Baffin Bay. Thus, information on the amount of sea-and berg-ice moving through this area and its characteristics i.e. floe diameters, berg dimensions, etc., is required. A measure was also sought of the extent to which ice tends to concentrate in or avoid prescribed areas of particular exploration interest.

2) obtaining all information possible on the physical dimensions, shapes and movements of icebergs and to a lesser extent of floe ice. A measure was also required of the winds and upper layer water currents which are believed to control berg and ice movements.

The specific components of the program consisted of:

1) An aerial iceberg survey by NORCOR Engineering Ltd. which utilized visual and radar techniques over a study area which consisted of a roughly 100 km wide strip extending roughly from 73°N latitude to 76°N latitude along the western edge of Baffin Bay. Berg counts were taken daily in the vicinity of potential drill sites. Elsewhere, less frequent bergs positionings and identifications were used to develop data on patterns of movement, speed-size distributions and other parameters.

2) Two land-based ice-berg tracking stations were maintained through the summer season. Seakem Ltd. maintained one of these on Hope Monument, Devon Island (Elevation 450 m). A second station was

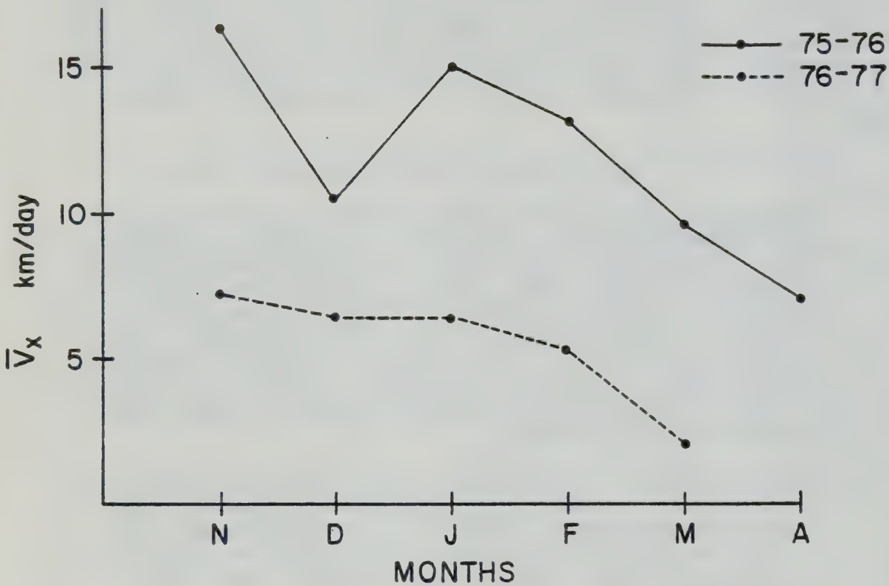


Figure 4-17: The East-West (roughly parallel to Channel axis) component of the monthly average velocities for November-April, 1975/76, and 1976/77.

all field results and the 1978 satellite imagery which, because of its resolution limitations, remains, in this instance, largely a tool for sea ice study.

4.1.4 Marine Geotechnics

4.1.4.1 Topographic Features of the Sea Bottom

Knowledge of the topography of the ocean floor is essential for an assessment of stability for drilling operations. Instability of the sea bottom may be encountered if steep slopes exist in the vicinity of the drilling location or if the bottom soil conditions are such that vibratory loading may increase the porewater pressure in unconsolidated soil strata to an extent that the soil grains liquefy and lose their shear strength. Also, drilling in areas with large boulders and stones on the floor or embedded under the sea-bed can cause serious top-hole drilling problems.

Isobaths indicated by maps produced by Petro-Canada's Atlantic Region Division, indicate that very few places have steep slopes, the maximum steepness being 3.3^{o} at a location in the Hope structure. The results of 1978 Echo Sound Survey are being processed with bathymetry being contoured at 2-5 m intervals which will allow for better determination of problem areas with the potential for slope failures. The Continental Shelf off Bylot Island is very narrow and reasonably smooth. Here, the slope is steep and, at the foot of the slope of the Marginal Channel, runs almost parallel to the coastline. Tectonic origins for the channel have been suggested, however, Grant and McMillan explain it as resulting from the scour from continental glaciers. These glaciers, in moving eastward, became loaded with erodable sediments at the edge of the so-called "tectonic hinge line" thus causing the marginal channel.

North of the Bylot Basin a distinct break in slope between the shallow and deep waters does not occur. The Basin gradually shallows from approximately 1000 m depth in the south to about 900 m at the Byam Martin site towards the north. This shallowing trend continues as far north as Smith Sound such that the 500 m contour runs E-W just north of the Bylot site. A similar gentle slope exists over the Philpot site but the trend of the slope is E-W, and isobaths run N-S. A banks-type shoal with less than 350 m water depths exist on the East of the Philpot structure and gradually deepens westward, draining into the marginal channel where the water depths are more than 500 m. The region resembles a submerged headland previously exposed to weathering. The gradual

collecting region for large concentrations of bergs (see for example the census data of Figure 4-19) which, under proper combinations of wind, current and sea ice distribution, move westward following the current patterns of the northern Bay. These can take bergs more or less directly across to the western side of the Bay where they turn southward again in accordance with the current patterns of the area. Alternatively, some bergs turn northwestward past Cape York and follow the Greenland coast in the general direction of Smith Sound before moving westward and joining the southward moving stream along the west side of the Bay.

Smith (1931) has emphasized the importance of remnant landfast ice in Melville Bay as a controlling factor in the rate at which bergs are released into the southward flow along the east coasts of Ellesmere, Coburg and Devon Islands. Bergs which remain less than approximately 35 km offshore follow the sea ice trajectories already discussed and turn southeastward into Lancaster Sound where they again usually turn southward and eastward re-entering Baffin Bay northeast of Bylot Island after, perhaps, being drawn into the eddy structures of the southeastern Sound. Iceberg census data in Lancaster Sound compiled by the Atmospheric Environment Service (Figure 4-20) and the m.v. "Orion Arctic" (Figure 4-21) are consistent with the described flow pattern. Characteristic areas of high iceberg density are evident along the major drift paths. Penetration of Lancaster Sound west of Navy Board Inlet is seen to be a relatively rare occurrence.

Those bergs which move southward somewhat more than 35 km east of Devon Island tend not to turn into Lancaster Sound but continue southward with the basic flow of Baffin Bay. There is some evidence that south of the latitude of Pond Inlet bergs tend to concentrate in narrow bands some distance off the western shore of the Bay. In 1978 such a band, roughly 15 km in width, was identified some 15 km east of the Bafffin Bay coastline in the vicinity of Clyde (Fissel (1978) pers. comm.). Bergs moving in this current often undergo multiple grounding - refloating events taking from 11 months to 3 years to move from their release point into the relatively warm waters of the North Atlantic.

The icebergs which enter the northwest Baffin Bay region can have masses as large as perhaps 100 million metric tons and drafts (maximum under-water depth) approaching 300 meters. Attempts to derive quasi-universal relationships between the maximum above-water heights and maximum drafts have been frustrated by the characteristic irregularity of the berg shapes. Thus, although the water-ice density dif-

berg grounding in water depths of 330 m in a fiord and in water depths of 230 m over a Cable have also been reported. Therefore, it is possible that the scour tracks observed at the Philpot site may be of recent origin and could be regarded as current activity. Only long-term studies may be able to confirm this speculation. If the scouring occurs frequently, exploration activities in the Philpot drilling area will require careful planning. Statistical analyses of the 1978 survey records will be done and studied in conjunction with other iceberg studies conducted by Petro-Canada consultants, E.P.O.A. projects, International Ice Patrol data and any other research work published in the literature. The purpose of this analytical approach will be to investigate if icebergs with drafts of the water depths similar to the Philpot drilling area scour and if they do, the frequency with which they traverse the area. The maximum scour depth encountered in this area will then be used to develop risk analyses at the drilling locations. A very rough estimate, however, indicates that icebergs with a draft more than 50 m constitute approximately 13% of icebergs sited by Marex Ltd. during approximately 2 1/2 month periods in 1972, 1974 and 1975 along with the east coast of Canada in Baffin Bay.

4.1.4.3 Surficial Sediment of Lancaster Sound - Baffin Bay

4.1.4.4 Introduction

In order to study the Baffin Bay area, east of Lancaster Sound, an extensive literature search was conducted and the information gathered combined with the results of analyses done on soil samples retrieved in 1978 from three locations. In addition to soil sampling, shallow seismic, side scan sonar, and echosounding data were recorded for the proposed Byam Martin, Bylot and Philpot drilling areas. Analyses are still in progress, therefore, no conclusions from this survey are reported herein. Some visual impressions from the raw data are, however, included to supplement the literature search.

4.1.4.5 The Sedimentary Scenario

In Baffin Bay sedimentation is generally controlled by three processes: Ice-rafted material has been recognized as a major constituent of the bottom sediment and bottom topography and currents have been recognized as controlling textural characteristics.

Many records, from early expeditions (cited in Perry (1961)) have accounted for transport of material by

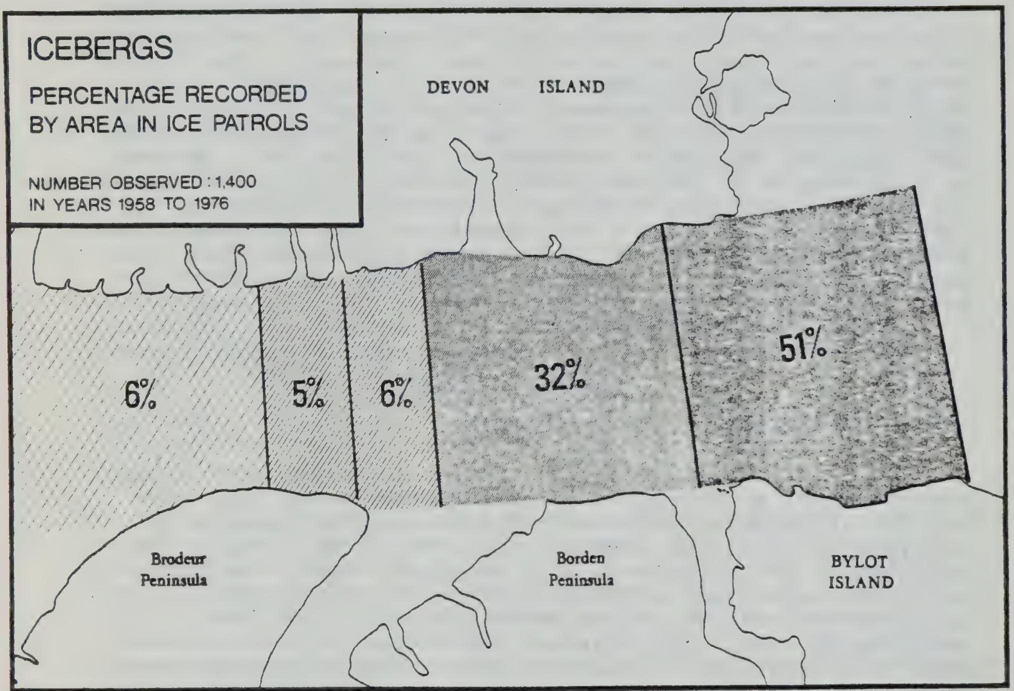


Figure 4-20: The percentage distribution by region of 1400 iceberg sightings by the Atmospheric Environment Service (Milne and Smiley, 1978).

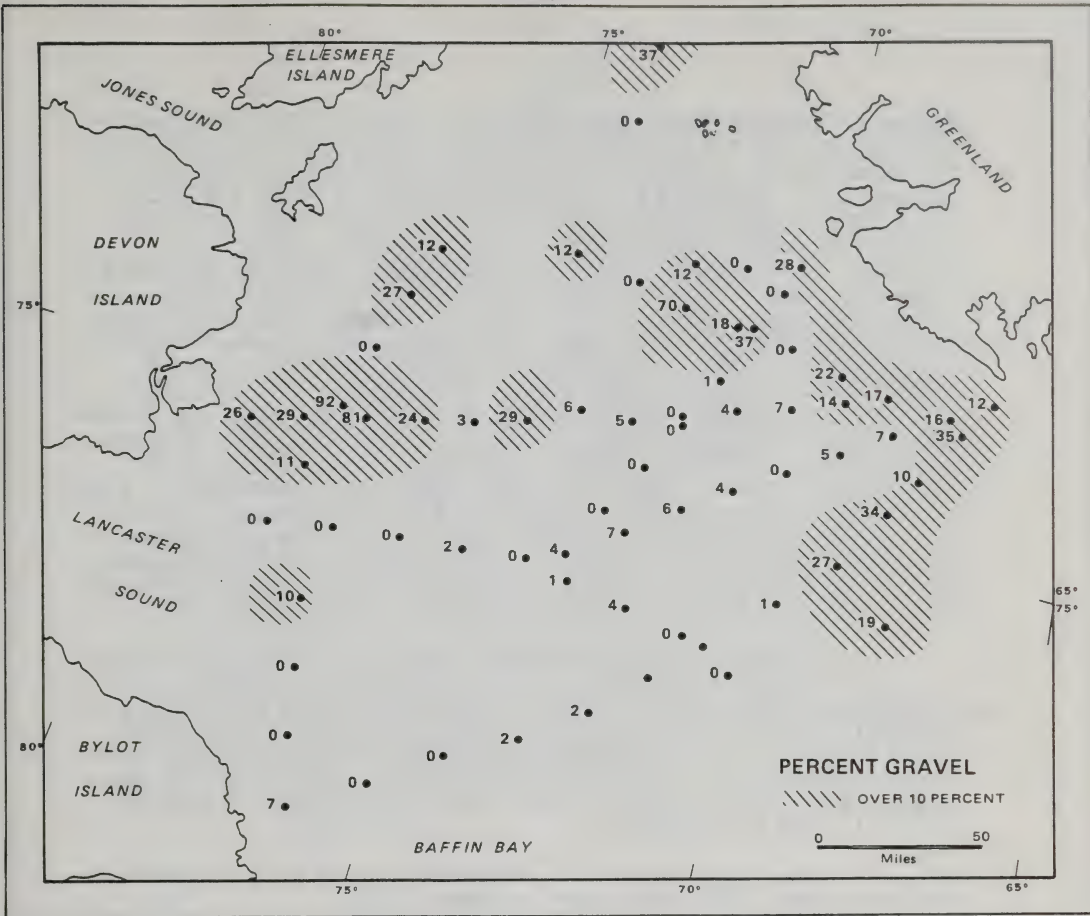


Figure 4–22 Percent gravel in the bottom sediment.
(after Grant, 1971)

ference dictates that approximately 7/8th of the berg mass is submerged, the irregularity of shape precludes any such simple comparable relationship between the maximum vertical dimensions. The great mass of measurements (see 4.1.3.2), also Smith (1925), Budinger (1960), Murray (1960) and Robe (1975) indicate that height to draft ratios range from roughly 1:1 to 1:11. The former value is normally believed only possible in the so-called "drydock" type of berg in which the above water portion takes an arch-like form having great height and little mass. At the other extreme it is expected that very low height to draft ratios tend to be associated with the "domed" type of berg which have smooth, rounded above-water portions and possibly taproot-like formations below the water line. However, a major study of these possibilities by Robe (1975) indicated that the standard deviations of the height to draft ratios for icebergs in each of the five major shape categories did not allow any simple assignment of height to draft ratios on the basis of shape classification. In part this result may be due to the small number of bergs surveyed (see Table 4-1) but it also reflects the limited validity of the classification process.

Thus, while an average value of 1:3.95 is descriptive of the overall results, some distinctions between the ratios characteristic of the pinnacle and domed categories is probably justified. It is possible for example to distinguish between the ratios characteristic of the pinnacle and domed categories. Other characterization possibilities may appear with more extensive data and the resulting improvements in the statistics.

By correlating the measured ratios with above-water heights Robe (1975) was able to show that:

1) taller bergs have a narrower range of ratios than lower bergs. The latter have height to draft ratios spanning the entire measured range of values.

2) the highest bergs tend to have the largest height to draft ratios.

Simplifications of the type sought in the Robe study, if valid, might significantly ease the data gathering requirements for a trajectory prediction system.

The dominant role of water currents in the movement of icebergs is well established (Smith, 1931). It has its origin in the much larger fraction of the berg's cross-sectional area which lies below rather than above the water

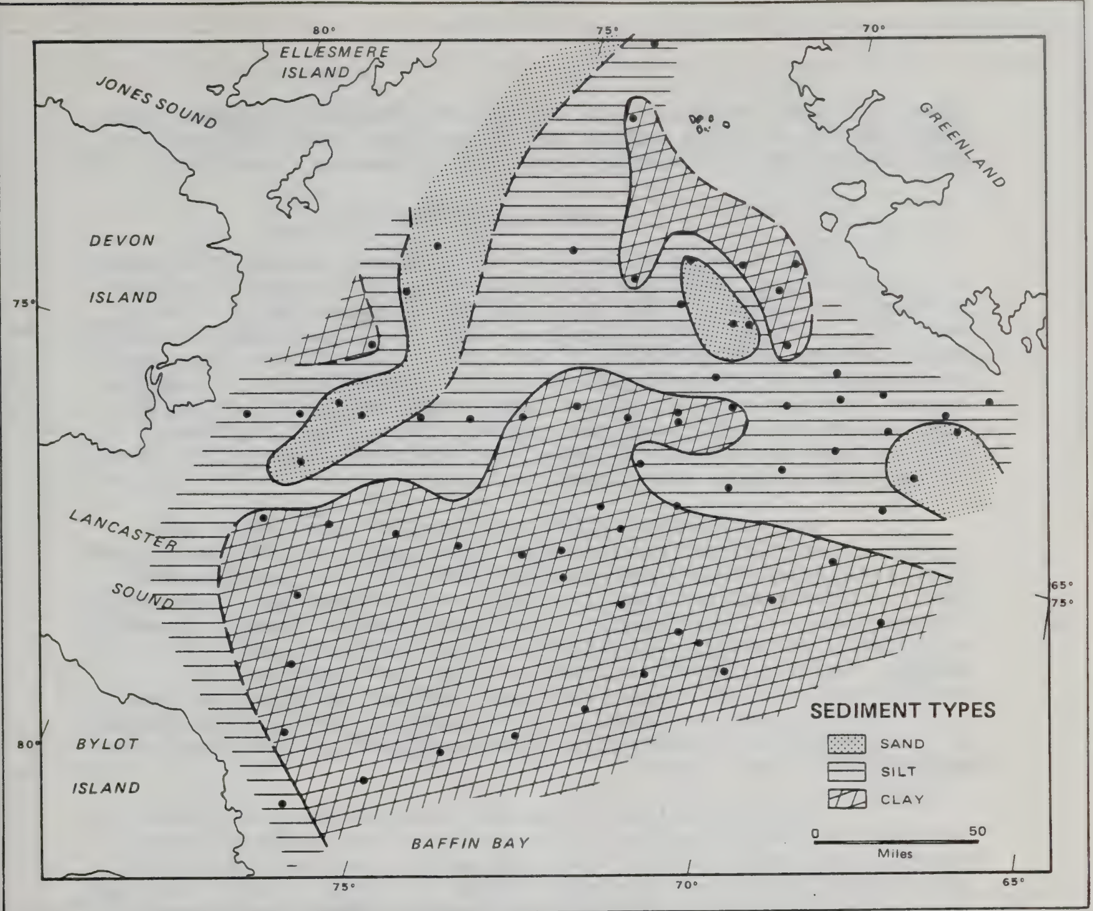


Figure 4–24 Sediment—type distribution on the basis of median grain diameters. (after Grant, 1971)

line. A great complication in motion prediction arises from the changing current speeds and directions seen as one moves down the water column away from the air-water interface.

4.1.3.4 Recent Developments

The accelerating pace of offshore resource exploration has greatly expanded our knowledge of the sea ice-cover in the years since 1950. Some of the information has been and will continue to be obtained from the steady accumulation of airborne ice-observations such as those used to construct the mappings of Figures 4-5 to 4-13. These data are a major source for the prediction of likely break-up and refreezing configurations and their associated timings and probabilities. They are presently being incorporated into atlas form by the Atmospheric Environment Service.

More recently, air-borne observations have been partially supplanted by the NOAA and Landsat series of satellite platforms which have greatly added to our knowledge of the ice movement patterns, landfast ice formation, lead development, etc. The "thermal" infrared sensors aboard the NOAA satellites have been of particular use in their ability to produce surface imagery, particularly that obtained over Baffin Bay, has only been, at best, cursorily examined and its study may aid materially, for example, in the development of long-range ice predictive procedures and in transport vessel route-optimization.

Data gathering on the sea surface has also been intensified utilizing the icebreakers of the Canadian Coast Guard, U.S. and Canadian Naval vessels, government research ships and commercial carriers. Some of these efforts such as the well-advertised cruise of the tanker "Manhattan" were largely concerned with the effects of ice on transport vessels. Nevertheless, some of the accumulated data such as the "Manhattan" ice thickness measurements obtained in Lancaster Sound, may yet be useful in evaluating models of ice growth and movement.

Significant advances in the large-scale mechanics of sea ice have evolved out of the research programs of the mid-1970's. The most prominent and fruitful of these was the AIDJEX (Arctic Ice Dynamics Joint Experiment) program which developed state of the art data-gathering and modelling techniques in the Beaufort Sea-Canada Basin sector of the Arctic Ocean. With appropriate modification and extensions these techniques may be applicable to the Baffin Bay system. It should be pointed out, however, that critical aspects of ice

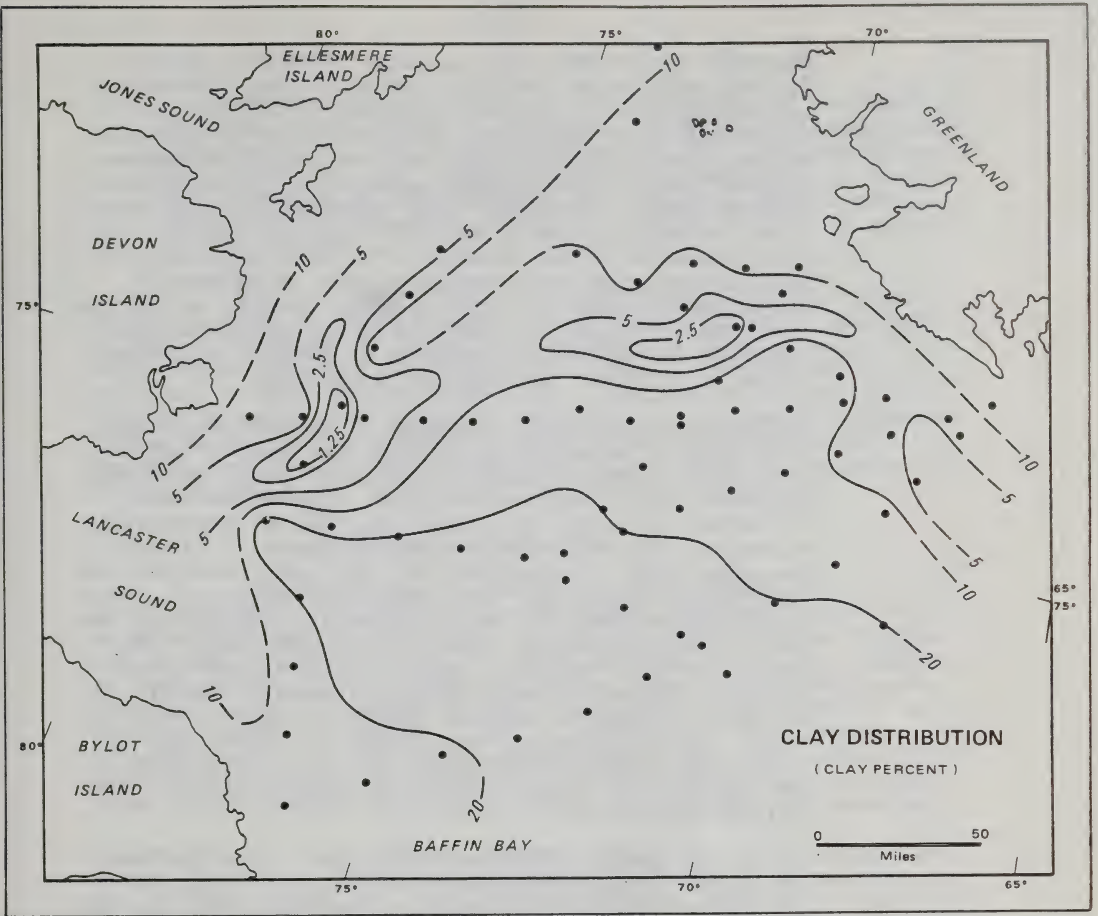


Figure 4–26 Clay distribution.
(after Grant, 1971)

operated by Nordco Ltd. on Cape Fanshawe, Bylot Island (elevation 596 m). In each case icebergs and sea-ice were tracked by radar at 20 minute intervals over distances ranging up to 45 nautical miles. Each station also gathered basic meteorological data. Additional automatically recording remote weather stations were operated at near sea-level sites at Cape Liverpool, Bylot Island and at Cape Sherard, Devon Island. The resulting high repetition-rate berg position data is presently being correlated with the deduced surface winds and measured currents in order to identify local patterns of movements as well as to deduce relationships appropriate to iceberg modelling.

3) Ten RAMS transmitters capable of giving positional data to ± 3 km accuracy through the Nimbus Satellite system were placed on selected bergs by Arctic Sciences Ltd. Above-water berg dimensions were estimated in each case from ship-board photography, radar-ranging and angular measurements. On the average about 5 positions per day were obtained for each berg, about half the expected data rate. This circumstance was due to a temporary shutdown in one of the satellite-receiving ground stations. The resulting data is still sufficient to give intermediate timescale position measurements over a several hundred kilometer length of berg trajectory. At the present date (January, 1979) all platforms remain operational and data continues to be compiled on iceberg drift along the Baffin Island coastline.

4) An Arctic Iceberg Dimension Project which derived the above water shape and dimensions of some 35 icebergs through quadrature photography and the use of a helicopter-borne altimeter. Almost at the same time, the draft of each berg was determined utilizing a sonar transducer lowered by winch from a hovering helicopter.

Attempts were made, where possible to correlate the above programs to maximize the length of trajectory tracked and the accuracy of the characteristic physical dimensions.

The emphasis on iceberg studies evidenced above reflects the judgement that sea ice represents a lesser threat to the proposed drilling program. This approach may be justified by the much lower numbers, in the summer season, of floes large enough in size to preclude deflection by tender vessels. Nevertheless, it is intended that the final Environmental Impact Statement will include an evaluation of

(2) If, however, the soil has a low porosity the stresses induced in the deposit tends to increase the porewater pressure. If the vibratory loading is for a sufficiently long time, the porewater pressure exceeds the shearing strength of the deposit and the soil grains are thrown into suspension forming a dense liquid of soil-water mixture.

The latter situation is detrimental to the structures founded on such soils. Here, where shipborn exploration is proposed, if liquefaction were to happen, either due to seismic activity or by any other means, it would not impose any threat to the operation. The potential for liquefaction also depends on soil-type the most susceptible being those which are non-plastic silts. The depth to which a deposit can liquefy again depends on the depth of unconsolidated sediment and the number of vibrations imposed.

4.1.5 Earthquake Zonations

The Baffin Bay - Lancaster Sound Basin (Fig. 4-27) is surrounded by clusters of earthquake epicentres, mostly with magnitudes of less than 5. Some earthquakes of larger magnitude (M greater than 6) have been recorded in a cluster of epicentres 150 km from this area. The largest known earthquake in the Canadian Arctic (magnitude 7.3) occurred in November 1933 (at about 73.2°N.; 70.0°W.) in this group of epicentres. A few large earthquakes have also occurred on and offshore, near Buchan Gulf. A cluster of smaller magnitude (less than 5) earthquakes are centered around Home Bay.

Figure 4-28 is the current seismic zone map for Canada produced in 1970. R-Factors mentioned in Table 4-28 are assigned to these zones to allow for earthquake loading in the static provisions of the building code. The damping effects of water and higher porewater pressure in ocean floor sediment may modify the R-Factor in offshore environments, but such a modification has not been documented in the literature on seismology. More scattered activity occurs in Lancaster Sound (less than 5) for offshore epicentres and one epicentre of larger magnitude (less than 6) occurs on Devon Island at about 75°N.; 85°W. (Fig. 4-28). Subsequent to the November 1933 earthquake, there have been earthquakes of magnitude 6 to 6.5 in Baffin Bay, during 1934, 1945, 1947, 1957 and 1963. Although approximately 14 epicentres of magnitude less than 5 have been recorded within a radius of 50 km of the area of interest in Baffin Bay, none of which would have been strong enough to produce an acceleration in excess of 0.01G at the locations of interest Basham, et al., (1977) indicate

shoaling trend is indicative of decreasing energy regimes and hence the deposition of more and more quantities of sediment derived from the Arctic islands.

Liquefaction of sea-bottom soils is chiefly a foundation problem and since no bottom-founded installation is anticipated it would probably not be of any significance during drilling (as discussed below). A literature search on the characteristics of the sea floor of Baffin Bay was carried out and in 1978 preliminary studies were done at specific sites. Soil samples from three location in Baffin Bay have been analysed in conjunction with preliminary side-scan sonar studies. The evidence from these initial studies indicates that no sizeable boulders or rocks appear to be present on the sea floor at the proposed drill sites.

4.1.4.2 Ice Scouring

It is believed that as many as 40,000 icebergs are produced every year from Greenland glaciers. They drift along the west coast of Greenland and Baffin Island coasts, and finally are caught in the Labrador current (Chari and Guha, 1978). In this process a large number of bergs are trapped in the bays and coastal indentations enroute and grounded permanently. An operator exploring in iceberg-infested waters must know about the frequency of icebergs passing over a given location. Chief among these concerns, especially during the exploratory phase, is the presence of banks in the area. These areas are susceptible to ice scouring and also grounding of icebergs. One such bank lies east of the proposed Philpot drill site. Iceberg surveillance records may be used in determining the iceberg grounding history of the bank. The 1978 sidescan sonar survey (still in the process of interpretation) indicated a maximum number of scour features in the Philpot area amounting to approximately 290 features. The Bylot drilling area had approximately 100 micro-relief features and the Byam Martin area had 44 long linear features which appear to be relict "glacial flutes", as they are different from normal sharp scour tracks. These features are gentle grooves and certainly, as an initial estimate, do not appear to be recent iceberg scours. It may be that scour tracks truncate at approximately 650 m water depth. It is possible that these deep-water scour tracks are old, or relict, since they may not be inscribed onto a non-depositional seabed and would not be obliterated by normal sedimentation.

Ice berg grounding in recent times have been documented by observations in water depths up to 448 m (Pelletier _et al._, 1974) off Thule by the Canadian Armed Forces. Ice-

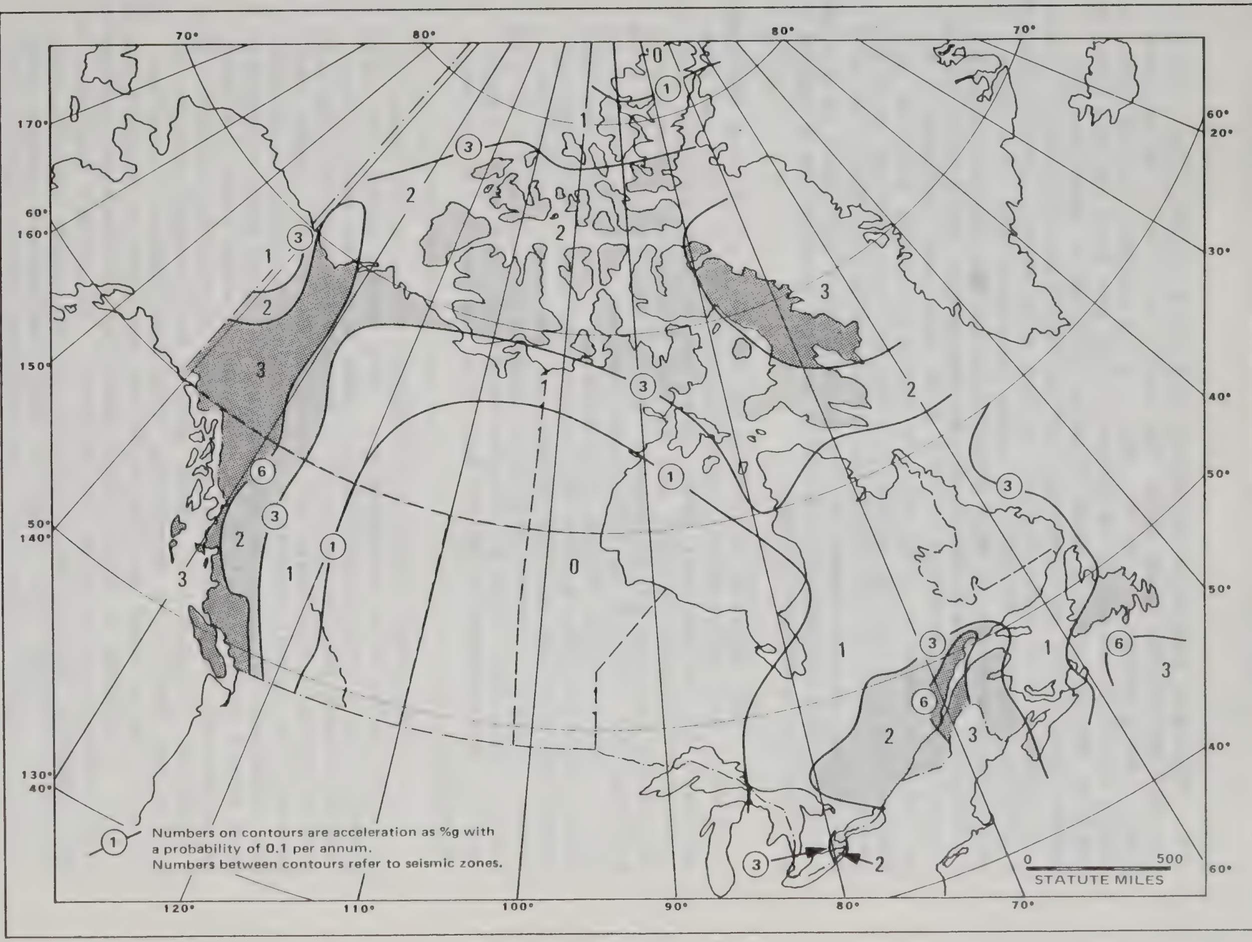


Figure 4–28 Preliminary Revised Seismic Zoning Map (1970) (from Science and the North 1972)

ice. The sea ice most probably exerts a greater influence on the sedimentation than does the berg ice, which is derived from land glaciers. As the sea ice is formed in the fall a great deal of material is frozen into the base of the ice in shallow water areas. When thawing starts in the spring, large quantities of material are moved onto the ice by flooding streams. If rain occurs at the same time, tremendous flooding, capable of moving large boulders down the slopes of hills, may occur. As the sea ice moves out from shore, it eventually melts and dumps its load, sometimes taking years to release the material if the floe does not completely melt during the summer. Some of the finer material stirred up during the process of grounding may be transported to other areas by currents and finer material released from ice will not deposit where there is any significant movement of bottom waters. The latter will deposit in the central deep water zone of low energy regimes.

The general distribution pattern of bottom sediment in Baffin Bay, therefore, is expected to show clays as predominant in the central deep water regions, gradually grading into silts, sands, gravel and larger fragments laterally shoreward into marginal zones. Particles greater than 2 mm and smaller than 75 mm are classified as gravel. Grant (1971) has plotted gravel distribution (Fig. 4-22) and samples exhibiting more than 10% gravel content expressed as weight percent of the wet weight of the total sample are shown. Sample numbers and their positions are shown in Fig. 4-23. From Fig. 4-22 it can be seen that the high gravel content approximately coincides with the paths of surface currents.

Sediment type distributions (Fig. 4-24) clearly show the effects of topography. Sand banks appear as topographic highs and the sediments show progressively finer trends toward deeper parts (i.e toward the marginal channel near shore and the Basin on the offshore side, around the banks). In actual practice clean or well-sorted sediments are uncommon deposits as they exist on multi-modal deposits. This means that a certain percentage of more than one soil type exhibit maxima in the grain size distribution curve for a deposit. Figure 4-25 shows such a multi-modal nature of Baffin Bay surficial deposits. The clay content in these deposits is plotted in Fig. 4-26 as contours of percentage of clay. It should be noted that low clay percentages indicate high current activity at the bottom. Laboratory analyses of soil samples from three locations in the south western part of Grant's study area agree in their mechanical properties with his regional picture. The textural distribution also agrees with the hydraulic model discussed above.

Table 4-2

Earthquake Intensity, acceleration and return period (Adapted from Energy, Mines and Resources).

Return Period (Years)	Intensity	Acceleration In Percent of of Gravity (A_{100})
3	I	0
10	III	0
30	V	1
50	VI	3
100	VII	5

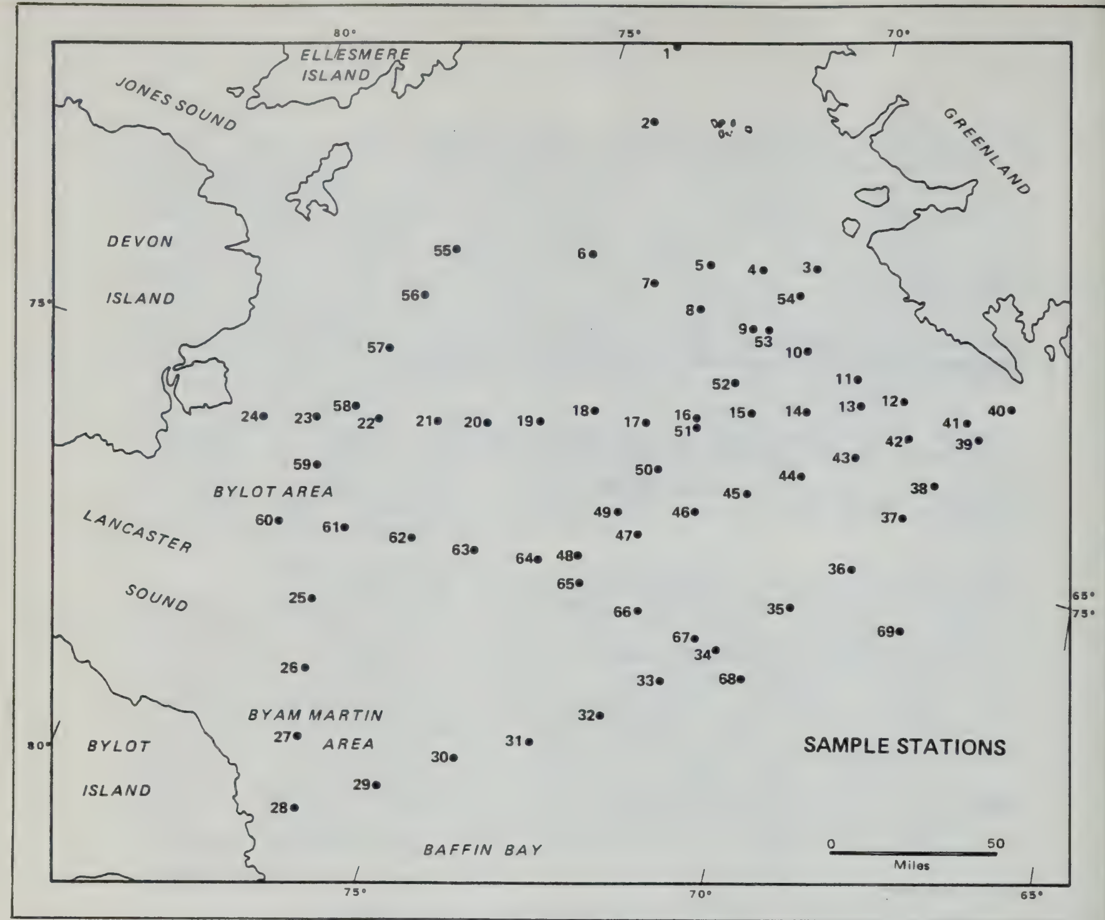


Figure 4—23 Sample station locations.
(Grant, 1971)

4.1.6 Baseline Levels of Petroleum Hydrocarbons in the Arctic Ocean

Levy (1977) reports the results of extensive oceanographic surveys carried out between 1971 to 1974 on the geographical distribution of floating petroleum residues in the North Atlantic. It was shown that tar was very rare in waters north of 45°N latitude which, the author noted, was a reflection of the remoteness of northern oceanic areas from major population centres and therefore from transport, production and consumption of significant amounts of petroleum.

In the northerly regions sampled the occurrence of tar was found to almost always be associated with recent shipping. Waters moving south on the east coast of Greenland and which exited from Davis Strait as the Labrador Current were found to be "essentially free from floating petroleum residues. Also free from tar pollution were the waters of Baffin Bay and the water exiting from the Canadian Archipelago....the only evidence of oil was in the vicinity of ports or areas through which ships had recently passed." (Levy, 1977). These observations were further supported by U.S. Coast Guard work which indicated virtually no pollution of waters between Greenland and Labrador but progressively higher levels of tar in the mid-Atlantic regions of the North Atlantic Current (McGowan *et al.*, 1974). Levy (1977) noted that these data were *indicative* of the strong association between the distribution of tar at sea and the surface current systems of the North Atlantic (Figs. 4-29 and 4-30).

More recently, survey research has indicated that natural oil seeps may exist in the vicinity of Scott Inlet, Baffin Island. This natural petroleum source is presently under investigation. Nevertheless, the Arctic Ocean must be considered to be in a largely pristine condition, as concerns petroleum hydrocarbon residues. While there have been large losses of petroleum (chiefly fuel oil lost from onshore storage facilities at settlements, as detailed elsewhere in this report) the Arctic marine environment and the biota that inhabit it must be considered to be largely unaccustomed to encounters with petroleum products.

4.1.7. Physical Oceanography

4.1.7.1 Introduction

The intent of this section is to provide a concise background for the readers of the forthcoming Environmental Impact Statement's section on Physical Oceanography.

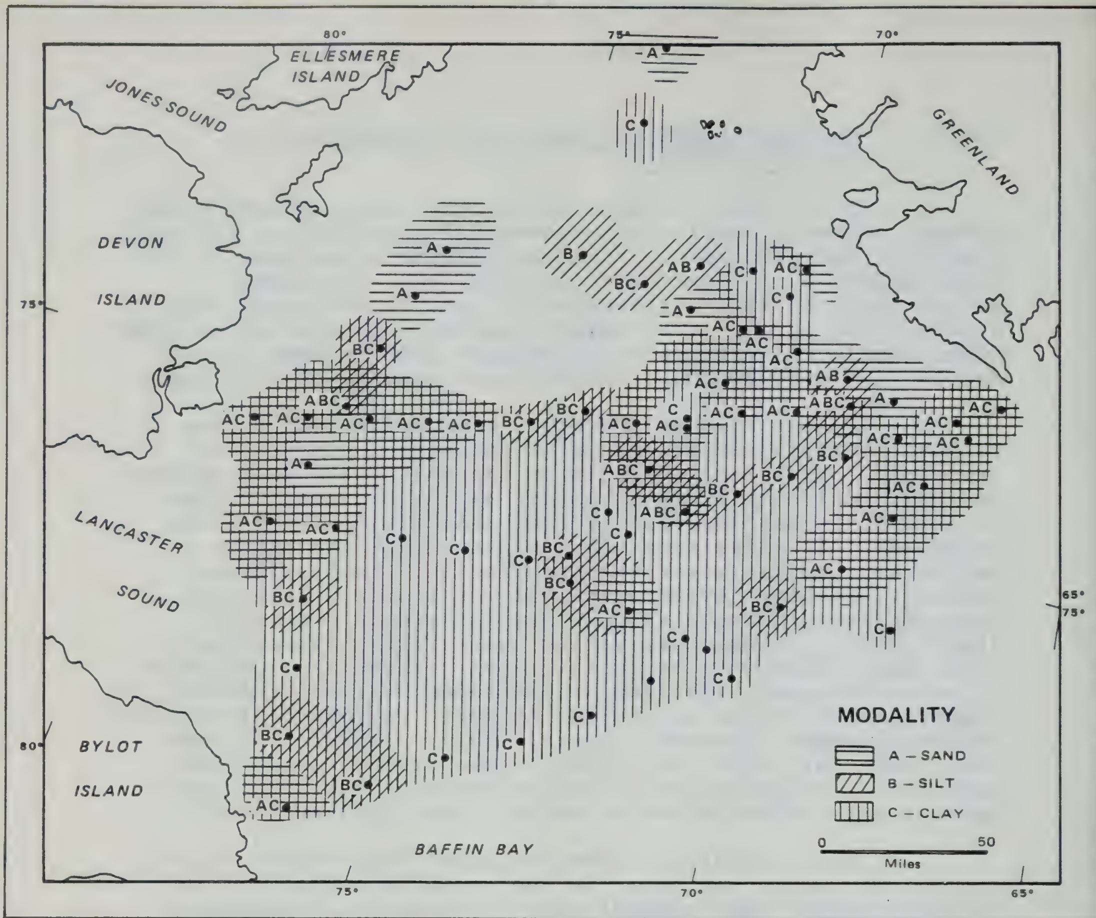


Figure 4–25 Position of the modes in size distribution of the bottom sediments.

The geological distribution of tar in the North Atlantic — E.M. Levy 1977

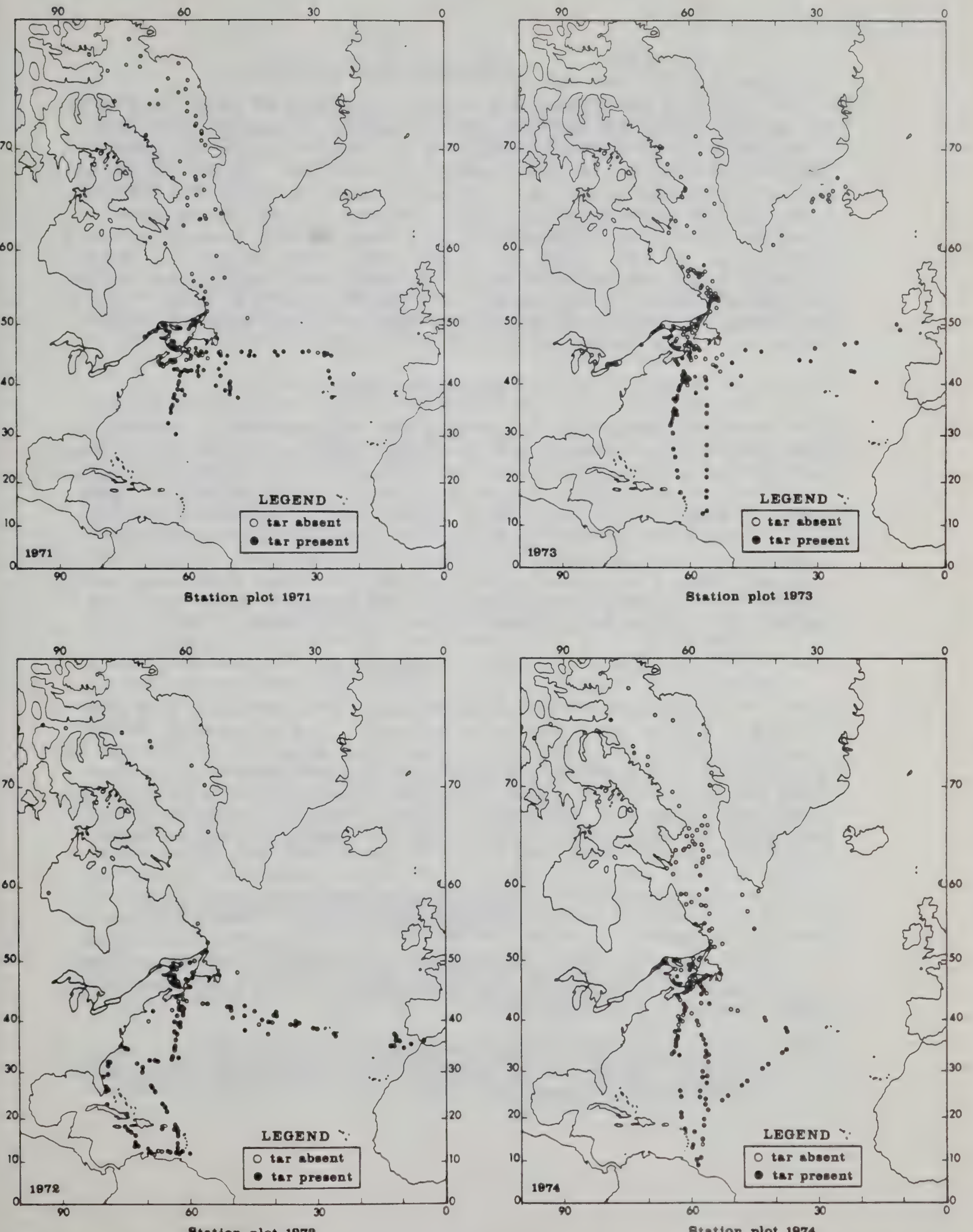


Fig.4-30

4.1.4.6 The Byam Martin Area

The average water depth encountered over this area is of the order of 800 m and the median diameter obtained from grain size distribution for the only sample analysed from this area is of the order of 0.004 mm. These agree with Grants' samples which were taken closest to Byam Martin and have median diameters of 0.0034 mm and 0.0045 mm respectively. The water content in the samples was generally very high being in the range of 92 to 139%. The surficial deposits in this area are found to be very soft while the unconsolidated layer, in general, is from 3 m to 6 m deep. The surficial sediment of this area may be classified as clay silts to silty clays of high plasticity.

4.1.4.7 The Bylot Area

Although the soil samples analysed from this area have still been classified as silty clays or clay silts, they have a low plasticity which is indicative of coarser material present. The analyses show that the samples contained some sand as well. The grain size distribution curves indicate that almost 80% of the material is coarser than 0.002 mm except for one location which shows almost 30% material coarser than #200 sieve (the boundary between fine sand and coarse silt). The gravel content in samples from both the sites (i.e. Byam Martin and Bylot) is minimal.

4.1.4.8 The Philpot Area

The soil here is silty clay or clay silt and contained not only sand but also gravel. The Atterberg limit analysis shows that the soil from this area had little or no plasticity. The water depths over the Philpot area ranged from 350 m to 400 m. The grain size distribution plots indicate approximately 10% gravel content showing that the Philpot site generally has more sandy or gravelly bottom material.

4.1.4.9 The Liquefaction Potential of Bottom Sediments

When a soil is dynamically loaded (i.e. when vibratory stresses are imposed on the deposit) the soil grains may react primarily in two ways:

(1) If the soil has a high permeability loading will tend to compact the soils by draining the porewater pressure of intergranular space.

4.1.7.2 History

The history of the Baffin Bay region naturally lends itself to division into a period of exploration for new lands to farm, hunt and log; and into a period of scientific investigation. The latter became possible only when the imperatives of survival in hostile regions no longer preoccupied mariners.

4.1.7.2.1 Prescientific explorations

The earliest existing references to the Baffin Bay region are found in the Norse sagas. Mowat (1965) has recently summarized the portions of these narratives relevant to Norse explorations in Greenland and Canada.

The Norse first entered Baffin Bay when in 982 Erik Thorvaldsson (The Red), in search of Irish settlement to plunder, sailed up the west coast of Greenland to Cape Burnil near the Arctic Circle and then across Davis Strait to Baffin Island in the vicinity of Cape Dyer (Fig. 4-31). Finding the Baffin Island coast unprofitable, he recrossed Davis Strait and the following year sailed farther north along the Greenland Coast to "Snaefells" which Mowat interprets as being the region near Melville Bay at about 75°N.

The coasts were found to be uninhabited and not particularly attractive for settlement but the ocean teemed with life, in particular sea mammals. The Norse settlers of Greenland apparently continued to hunt on the northern coast of west Greenland for centuries. A party wintering near Upernavik around 1300 inscribed a rune stone which was later found.

The Greenland Norse, being highly security oriented were disturbed by the inroads of Skraelings (Inuit) on what the Norse deemed their domain. In 1266 they sent an expedition into northern Baffin Bay to discover where the Inuit (members of the Thule culture who had recently appeared in northwest Greenland) had originated. One can only presume that the intention was to persuade the Inuit by unsubtle means to cease their migrations southward. This expedition apparently reached Devon or Bylot Island. Evidence of Norse explorations in Lancaster Sound and Barrow Strait exists in the form of a stone tower found by Lt. S. Osborne of the British Navy on Cornwallis Island in 1850.

The little climatic optimum came to an end in the 13th century and explorations tended to be confined to more southern latitudes. The next people to enter the Davis

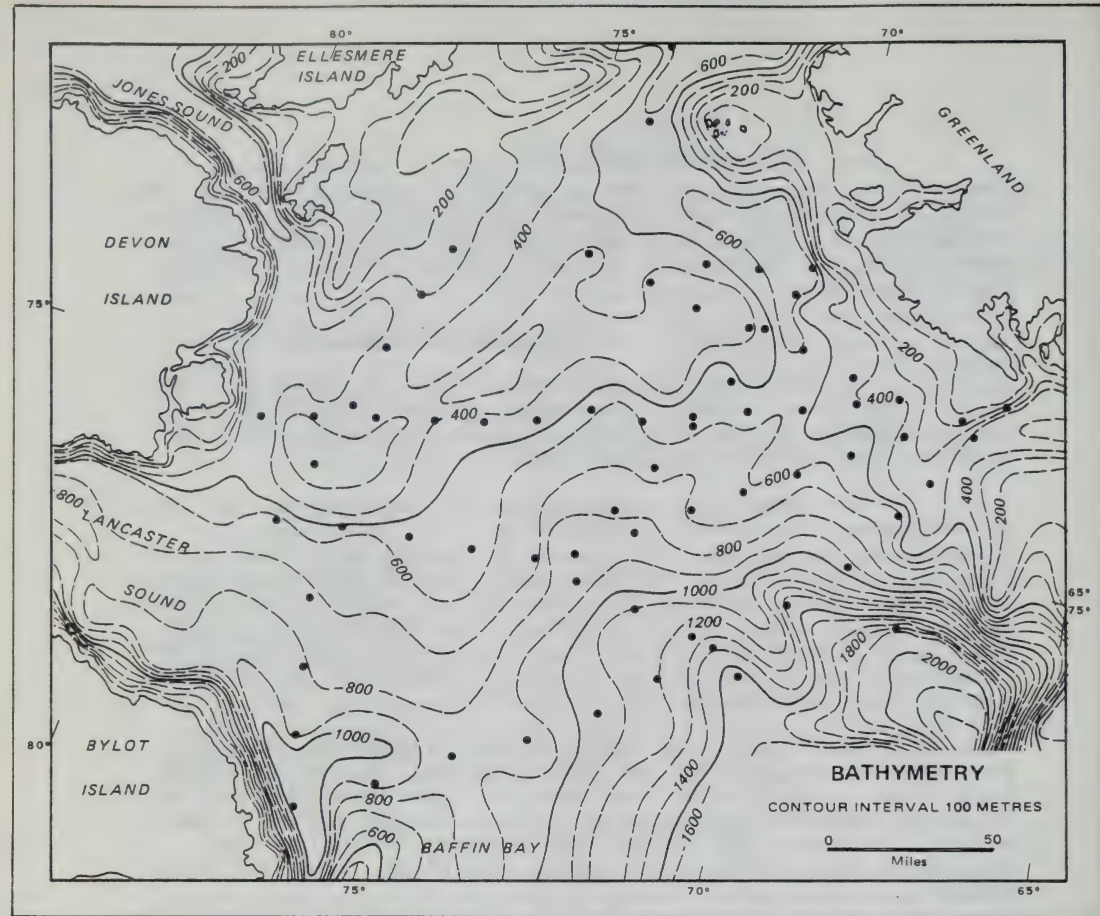


Figure 4–27 Detailed bathymetry of the study area.
(ater Grant, 1971)

Strait region were probably Basque whalers in the 15th century.

Some time in the 15th century the period of prehistory, when oral tradition was the primary means of communication between generations, ends. Exploration by the peoples of the European continent took up where the Greenlandic and Icelandic ceased. Many of these explorations were recorded and the original documents are still in existence. In 1476 a joint Scandinavian - Portuguese expedition sailed to Labrador which no doubt stimulated interest in exploration of the marine resources of the area. The voyages of John Cabot in 1497 and Caspar and Miguel Cortoreal in 1500 effectively introduced knowledge of the Labrador Sea and Newfoundland to the governments of Britain and western Europe.

Between 1576 and 1578 Martin Frobisher made three voyages to southern Baffin Island. The first recorded non-Norse voyages to the waters of Davis Strait and Baffin Bay were made by Davis in 1585-1587. In 1616 Bylot and Baffin sailed through Baffin Bay, through the pack ice and into the "north water" reaching a latitude of 77°25' where they were stopped by south flowing pack ice. On the return voyage both Jones and Lancaster Sound were sighted. The newly discovered lands of the North American continent, in particular those around Hudson Bay, diverted the attention of European explorers until the early 19th century. Meanwhile Dutch and Danish whalers established the Davis Strait whale fishery in the early 18th century.

The north Baffin Bay whale fishery was begun in 1817 with the arrival of the whaling ships "Larkin" and "Elizabeth" in the north water. As is apparently often the case, the commercial adventurers were closely followed by the agents of their governments. In 1818 Britain returned to explorations of the Arctic. In this year Ross explored Baffin Bay and sailed a short distance into Lancaster Sound and concluded that it was closed off by land. The next year Parry, not convinced of Ross's conclusion, returned to Lancaster Sound and sailed to McClure Strait. Water samples and temperatures were taken at various depths - the first precursor of the scientific investigations which would begin in earnest during the next 50 years.

In 1845 John Franklin entered Lancaster Sound seeking a northwest passage. His ship became ice bound near Prince William Island and was abandoned, the survivors attempting to reach the Back River over-land. Forty expeditions were dispatched to find the missing Franklin expedition between 1847 and 1859. This concentrated effort contributed

that a linear trend is not obvious particularly from recent earthquake records (1962- 1974).

In general, no earthquake damage is sustained below magnitude 5, hence earthquakes of M less than 5 recorded in and around the exploration area do not pose any threat to the exploration activity. Moreover, the chances that an earthquake of sufficient magnitude to affect the operations occurring during a single drilling season are very slight.

An initial assessment of the surficial sediment at the sea bottom shows that low to high plastic, silty to sandy clays constitute the sedimentary deposits lying on fairly flat bottom (maximum slope at one location is 3.3^{o}). The chances of a slope failure or mud slumping in this area are low. Low plastic silty/sandy soils may however liquefy to a small depth from the sea bottom, if a strong earthquake did occur. But this should not be considered any threat to exploration activities as no large structure is being supported by the ocean floor during ship-born drilling operation. The BOP, being supported by a long pile casing string would be unaffected by any soil liquification in the upper four metres.

An estimate of earthquake probability of a site selected within the area of our interest in Lancaster Sound-Baffin Bay, has been provided by the Seismology Division of Earth Physics branch of Energy, Mines and Resources. The analysis includes earthquakes between 1899 and 1976 inclusive.

The site experienced a maximum acceleration of 4% of gravity or a maximum intensity of VI, once during this 78 year period. The analysis predicts the probability of recurrance of a given earthquake intensity (Modified Mercalli Scale) or an acceleration as percent of gravity. The computations show that over a period of 53 years negligible accelerations were reached by assuming extreme-values for earthquakes in the last 25 years. Using the entire record of 78 years Table 4-2 was computed. The table indicates that for exploration activity which lasts a maximum of 4 months, the design return period of 10 to 30 years is reasonable, which gives negligible accelerations at the proposed site and, therefore, the operation is well within the permissible risks.

Table 4-3 correlates acceleration "A_{100}", as percent of gravity with an average annual probability of 1 in 100 that will be exceeded, with onshore damage rating and the corresponding zonations.

and salinity characteristics. A warm, saline Atlantic water layer was found below a layer of fresher cold Arctic water.

The period of purely oceanographic expeditions began in 1883 with the Swedish Sofia expedition led by Nordenskiold, (known for his Northeast Passage transit). Water samples were taken and temperatures measured to depths of several hundred metres with reversing thermometers. The West Greenland Current was described as having a cold low salinity upper layer, a warmer and more saline mid-depth layer and a deep layer colder and slightly less saline than the middle layer.

Between 1884 and 1887, a Danish naval expedition in the Fylla greatly contributed to the oceanographic knowledge in the Davis Strait region. Hydrographic sections were occupied between Godthaab and Svartenhuk Peninsula in latitude 71^{o} as well as off the Baffin Island coast. The results of these expeditions established that a southward current flows down the Baffin Island coast into the Labrador Sea; a mixture of Atlantic and East Greenland polar water forms the West Greenland Current; and the West Greenland Current branches at the Davis Strait ridge, part turning to the west and part continuing north along Greenland. Surface currents deduced from ice drift were recorded in 1898-99 on the "Windward" expedition in northern Baffin Bay.

In 1900 Peterson analyzed the existing data and described two currents flowing southward from Baffin Bay. One along the western shore from Smith Sound to Davis Strait and one beginning near Cape York and joining the other in Davis Strait. The "Tjalfe" expedition of 1908-09 provided data which implied that the deep waters of Baffin Bay originate in the Arctic Ocean, indicating a southward flow through Smith Sound and a net inflow through Jones and Lancaster Sounds.

The "Titanic" disaster occurred in April 1912 and led to the establishment of the International Ice Patrol under the U.S. Coast Guard. Surveillance of icebergs in the shipping lanes was quickly expanded to include predictions of the severity of upcoming seasons. Knowledge of the Baffin Current as well as the Labrador Current became essential and stimulated further measurements in the Baffin Bay region.

The 1928 expedition of the"Godthaab" had as its primary objective the investigation of the course and extent of currents in Baffin Bay as well as the extent and the influence of the Atlantic Water. In 1939 Kiilerich constructed dynamic sections from the "Godthaab" data which indicated

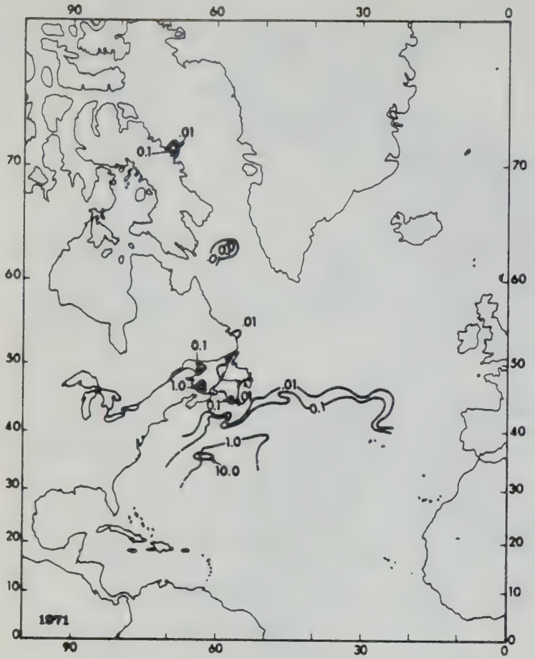
Table 4-3

Correlation of acceleration as % gravity, shown as annual probability in the drilling area.

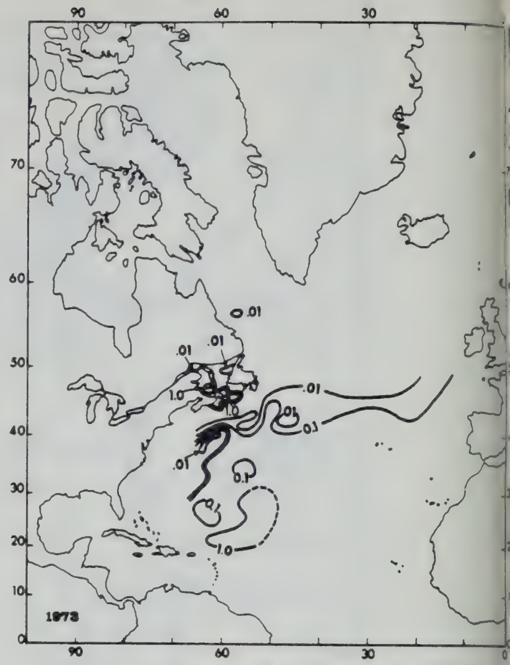
LIMITS			ZONE	R-FACTOR	DAMAGE
0	A_{100}	1% gravity	0	0	0
1	A_{100}	3% gravity	1	1	minor
3	A_{100}	6% gravity	2	2	moderate
6	A_{100}	6% gravity	3	4	major

Figure 4–32 The bathymetry of Baffin Bay.

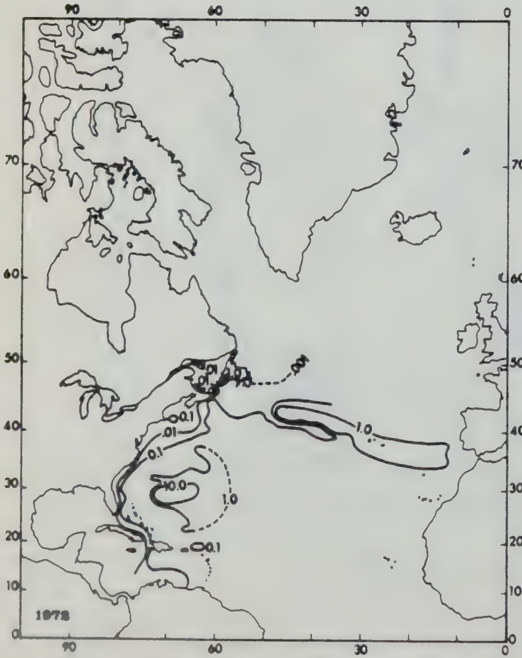
Adapted from Levy, 1977



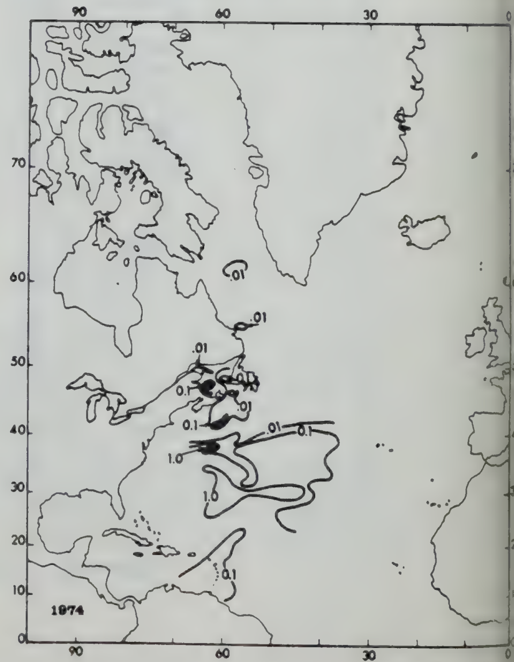
Contour map of tar distribution, 1971



Contour map of tar distribution, 1973



Contour map of tar distribution, 1972



Contour map of tar distribution, 1974

Fig. 4-29

A temperature-salinity diagram for the Baffin Bay region for depths below 50 m has been constructed from representative stations of several cruises from 1928 - 1979 in (Fig.4-33). Due to the great variation of water properties with the season at shallower depths, these near- surface data have been excluded. The intention of this figure is to broadly define the four major water masses and not to convey detail. The cold, fresh Arctic water is below 0°C and has a broad range of salinities which are, however, generally below about 34°/oo. This water is found at depths of up to 300 m in the Baffin Current, but is confined to increasingly shallower depths with increasing distance from Baffin Island. In the Baffin Current, Arctic water extends to the surface during the winter where it is at its freezing point beneath the sea ice. Local warming during summer however, can raise the temperature of the near surface layer to +3°C or higher.

Baffin Bay Deep Water fills the basin at depths greater than 300 or 400 metres. The salinity range of this water mass is 34.0°/oo to 34.7°/oo while the temperature range is roughly -1°C to +1.5°C. This water is a mixture of Labrador Sea deep water and the surface water of the Baffin Bay region, and as such is clearly distinguishable from the deep water of the Labrador Sea, Atlantic Ocean and Norwegian Sea which has a characteristic salinity of 34.92°/oo.

Labrador Sea water is characterized by the highest temperatures and salinities in the region: +0.5° to 4.0°C and 34.6 to 35.0°/oo. This water is present only in small quantities in the Baffin Bay region since most of that carried by the West Greenland Current is recirculated to the Baffin Current at the Davis Strait Ridge. The relatively high salinities and temperatures show that waters of Atlantic origin are an important constituent. The Labrador Sea water is confined to the southeastern sector of Baffin Bay at depths of more than 200 - 300 m.

The waters over the Greenland continental shelf are relatively warm and fresh. This is due to low salinity source waters from East Greenland and coastal water input. The warming is, in part, a local process but is mainly due to advection of warm surface water (temperatures up to 10°C) along the Greenland slope and shelf from the Labrador Sea. The two T-S traces shown in Figure 4-33 demonstrate the very different water mass signatures which may be found in the Baffin Bay region.

Instruments and methods in physical oceanography have become increasingly complex since the introduction of reversing thermometers in the late 19th century. The complexity and sophistication of the instruments have been reflected in the detail in which marine systems have been described, analyzed and modelled. Up to 1950 however, the major technique in physical oceanography was the dynamic method, based on temperature and salinity data. This method provides a general rather than a detailed view. For this reason, we provide in this report a summary of the salient features of the physical oceanography of the Lancaster Sound, Baffin Bay, Northern Davis Strait region reported before 1950. In this summary we present the generalities of the oceanic motions established before the common use of direct current measurements, which will, hopefully, serve as an introduction to the more detailed report to follow.

The waters discussed herein include Lancaster Sound, Baffin Bay and Davis Strait south to the Arctic Circle (the latitude of Cape Dyer). The region lies wholly within the Arctic where oceanographic observations have never been made with the relative ease experienced in more temperate latitudes. What are considered routine observations in lower latitudes have necessitated expedition style data gathering efforts in remote Arctic waters so that the oceanographic knowledge of these regions has lagged behind that of temperate seas where population centres are often close by. With these cautions in mind, and remembering the hardships that the early explorers experienced, and the effort required to survive, let alone collect oceanographic data, one can better appreciate the knowledge that had been accumulated before recent times.

In this interim report, because of limited time, we arbitrarily limited the presentation to the developments before 1950. We have attempted to present the relevant findings and have usually omitted those which were later proved inaccurate. Also in this report is a brief description of the field work undertaken in 1978. There will certainly appear to be a gap between 1950 and 1978. We have performed a literature search of the more recent material before embarking on the field program and will include a more comprehensive summary of this more recent work in the forthcoming Environmental Impact Statement.

This document is intended to serve as an introduction to a future report with an up-to-date literature survey and a description of the data collected during the 1978 field year before June 1979.

The distribution of temperature and salinity at 100 m depth taken from Dunbar (1951) is shown in Figures 4-34 and 4-35. The isohalines in particular show the division of Baffin Bay into an Atlantic dominated eastern regime and an Arctic dominated western regime. In the absence of diffusion and vertical shear the isopleths are stream lines. As such, they clearly indicate low salinity input from Smith, Jones and Lancaster Sounds and the blocking effect of the Davis Strait Ridge where waters of the West Greenland Current are largely redirected west then south.

4.1.7.3.3 Currents

Knowledge of the currents of the Baffin Bay region before 1950 was based on the dynamic method applied to hydrographic data and on the drift of ships. The dynamic method has certain limitations which can be very pronounced in weakly stratified waters such as those found in high latitudes. Such computations, however, are usually a fair indication of the relative strengths of mean (time averaged) currents. Figure 4-36 shows the surface currents in the Baffin Bay region (speeds in cm s^{-1} as first compiled by Dunbar, (1951)).

The general pattern of circulation in the Baffin Bay region is cyclonic or anti-clockwise. That portion of the West Greenland Current waters which has not been turned westward at the Davis Strait ridge flows north in the eastern region turning to the northwest in Melville Bay. The Baffin Current appears to originate in Smith Sound which is, in turn fed by Arctic Ocean outflow through Nares Strait. The southward flowing current is enhanced by the flow through Jones Sound. Upon reaching the south coast of Devon Island, a branch of the current follows the isobaths westward into Lancaster Sound a distance of 30 to 150 km before turning southward, crossing Lancaster Sound and then flowing eastward, further enhanced by the Arctic Ocean outflow through Parry Channel. The Lancaster Sound outflow rejoins that portion of the Baffin Current which was not directed into Lancaster Sound at Bylot Island where the flow continues southward down the coast of Baffin Island.

Clearly, the currents are very strongly influenced by the bathymetry. Such effects can only be present if the current persists with depth to the bottom planetary boundary layer. This condition requires an uncompensated pressure gradient at the bottom (a barotropic component of flow). The relatively weak stratification encountered in Baffin Bay is a strong indication that sea surface slopes may not be compensated by the mass field at depth. In other words, the ocean

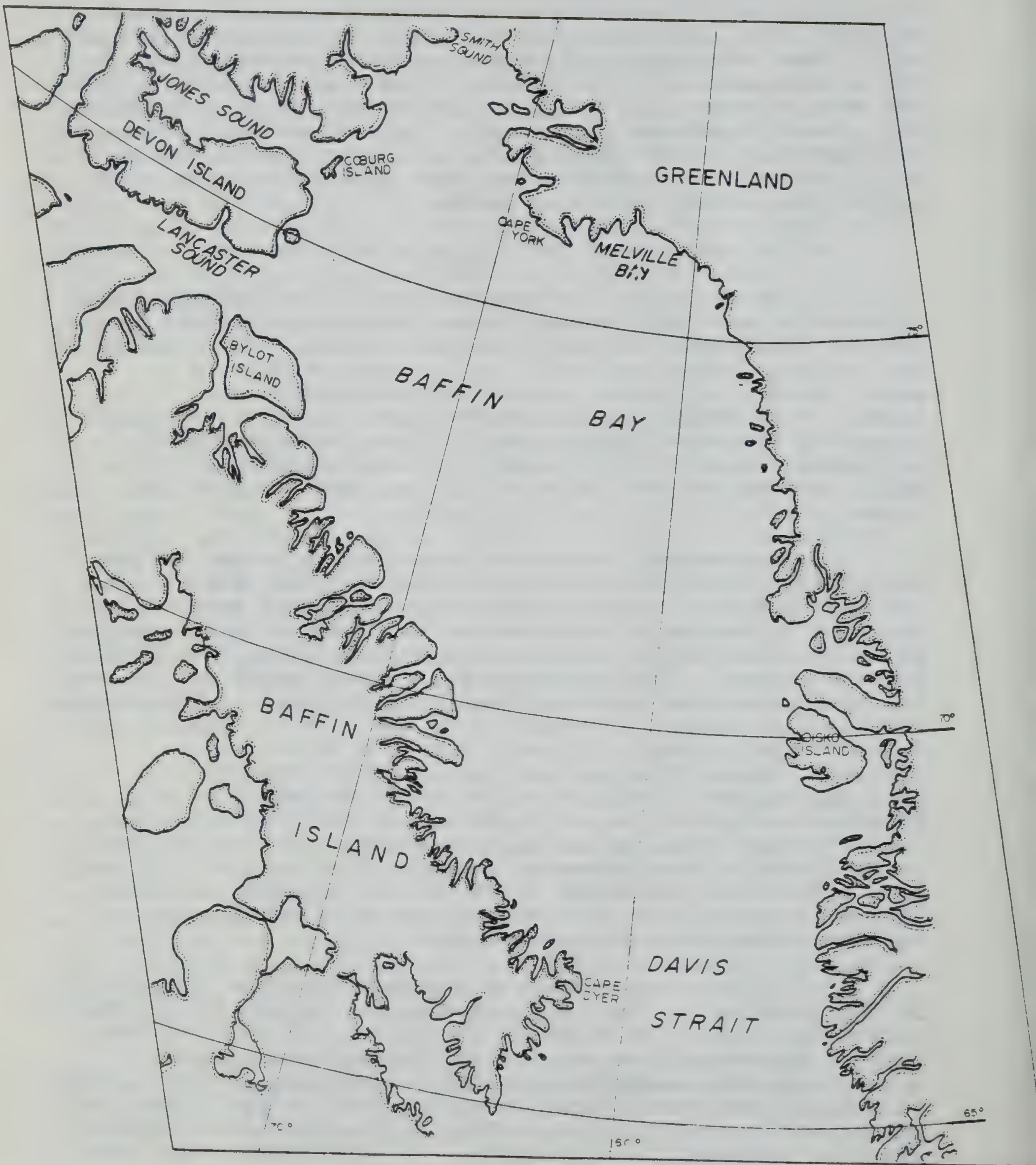


Figure 4-31: The Baffin Bay Region.

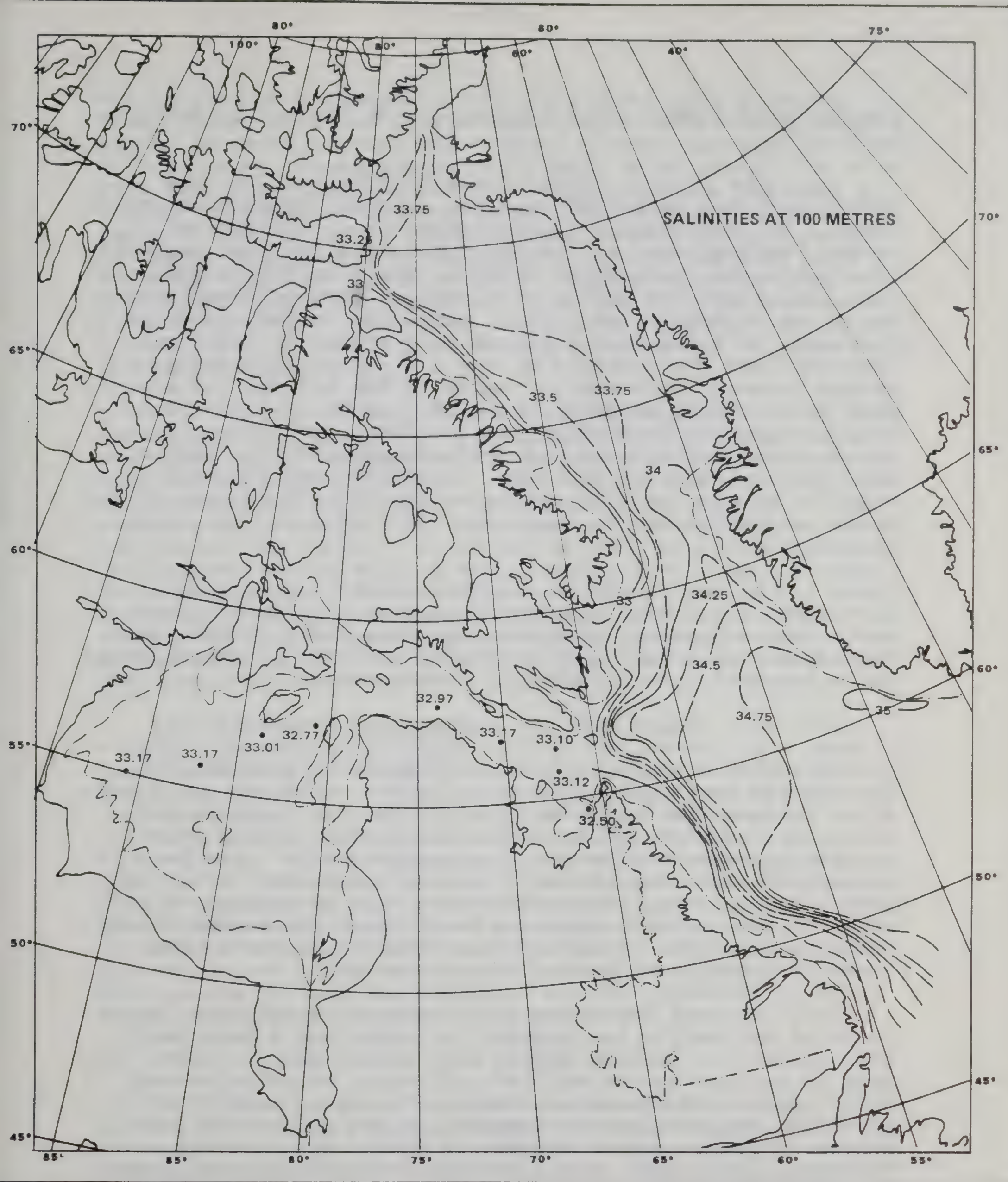


Figure 4–35 Salinities at 100 metres, August-September. Composite figure from various years. (From Dunbar, 1951)

greatly to the geographical knowledge of the Arctic Archipelago.

The British Arctic Expedition during the late 1840's explored Baffin Bay and the channels west of Lancaster Sound. The two vessels "Investigator" and "Enterprise" became icebound west of Lancaster Sound but drifted eastward into Baffin Bay near Bylot Island. The ship drifts were, then, the first indication of a current flowing from Lancaster Sound to Baffin Bay. Three more ship drifts added to knowledge of the currents around this time. In 1850 the "Advance" and the "Rescue" of the U.S. Grinnell Expedition became icebound just west of Devon Island and drifted southward and eastward to Baffin Bay, then south to Davis Strait. In 1852 the Inglefield party in the "Resolute" became icebound in Lancaster Sound and drifted eastward into Baffin Bay, then southward. The "Fox" in 1857 became icebound in Melville Bay and drifted southward from Cape York through the centre of Baffin Bay to Davis Strait. (Refer to Fig. 4-15, Section 4.1.3).

By the middle of the 19th century, geographical knowledge of the Lancaster Sound, Baffin Bay, Davis Strait region was relatively complete, and some basic current patterns had been established from ship drifts. Attention began to be focussed upon scientific investigation.

4.1.7.2.2 Scientific Investigations

The transition from exploration to scientific inquiry was very gradual so that the choice of any one expedition to mark the beginning of a new era is, by necessity, arbitrary. The Hayes expedition aboard the "United States" in 1860 however, due to its findings, might be taken as a convenient beginning of the cruises whose primary goal was scientific inquiry. This expedition made soundings and ice observations in Baffin Bay and Smith Sound and measured temperatures at depth. Warm water of Atlantic character was found at subsurface levels in northern Baffin Bay.

In 1867 Petermann summarized the geophysical knowledge of the Baffin Bay region. He described a warm northerly current in eastern Baffin Bay, a cold south flowing current in western Baffin Bay and cold water entering through Smith, Jones and Lancaster Sounds. The Nares expedition of 1875 made observations of temperature and chlorinity to depths of 210 m between the Arctic Ocean, Nares Strait and Southern Baffin Bay. These observations allowed the identification of various water types based upon their temperature

may respond to atmospheric forcing without such response being fully reflected in the hydrographic data. Such flows cannot be detected with the dynamic method, but require direct current measurements which must be obtained with current meters or drifting floats. This situation provides a strong arguement for direct current measurements in this region. Dunbar (1951) shows an eddy in Baffin Bay east of Lancaster Sound which is based primarily on the work of Kiilerich (1939). Since Dunbar's surface currents have been reproduced in the Arctic Pilot, this current pattern has had wide distribution. It is of interest to note however, that this feature is the only major one which cannot be related to the bottom topography.

Since the great majority of hydrographic work in the Baffin Bay region has been performed during the summer and early fall, information on the seasonal variation of the currents is largely lacking. In addition (for reasons which will not be discussed here, but in the final report) it is probable that the density field cannot respond rapidly enough to reflect the current variations on time scales of months. Once again, direct current measurements are necessary; in this instance to illuminate the time variations of the mean currents. It is quite probable, however, that the local warming of surface waters which occurs in summer does cause an increase in the flow of the near surface currents through the mechanism of geostrophic adjustment.

Tidal oscillations of surface height have associated with them tidal currents. It is however, not generally possible to deduce the tidal currents from knowledge of the tidal heights. Tidal currents are important in this region, perhaps achieving speeds of 20 cm s^{-1} locally, but only direct current measurements can adequately measure these flows. The dynamic method (density measurements) can provide no information on the tidal regime. In addition, a proper analysis of tidal oscillations requires a record of at least one month's duration with samples taken once per hour. The only instrumentation which is capable of obtaining such information is a moored internally recording current meter. The results of such measurements will be presented in the final report; some preliminary results are discussed below.

4.1.7.3.4 Tides

Tidal height observations have been made in the Arctic for over a century. These require only the recording of water levels at hourly intervals over a period of a month. The knowledge of tidal heights in this region was therefore, considerbly more complete than that of currents in 1950.

major north and south flowing baroclinic currents along the east and west shores of Baffin Bay, respectively; a cyclonic gyre in the northern portion of Baffin Bay and intensification of the northwesterly flowing current southwest of Cape York.

Also in 1928 the U.S. Coast Guard vessel "Marion" made a series of measurements in the waters southeast of Baffin Island. The work was later continued with the several cruises of the "General Greene" in 1931, 1933, 1934, and 1935. This work was reported and analyzed by Smith, Soule and Mosly (1937) and combined with the "Godthaab" data provides us with the majority of our knowledge of the Baffin (or Canadian) current system which flows southward along Baffin Island. The 1940 "Northland" expedition, due to unusually light ice conditions, accomplished a hydrographic survey in the Baffin Current, complementing the data existing by that time. The results showed two counter currents embedded in the Baffin Current.

The war forced a cessation of offshore scientific investigation in this region. Immediately following the war however, there was a flurry of activity in the form of Canadian and U.S. military and coast guard operations. Meteorological stations were established in the eastern Arctic and icebreaker cruises were undertaken as far west as Melville Island. Intensive oceanographic study of the Baffin Bay region took place in the late 1950's and 1960's and will be chronicled in the final report.

4.1.7.3. Oceanographic Introduction to the Lancaster Sound-Baffin Bay-Davis Strait Region

In this section we review the bathymetry, water masses, currents and tides of the region. The bathymetry and water mass sub-sections contain up-to-date information whereas the currents and tides sections contain only those data and conclusions available before 1950. Recent information on tides and currents acquired after 1950 will be presented in the final report.

4.1.7.3.1 Bathymetry

Baffin Bay consists of a deep basin offset slightly to the west of the mid point between Greenland and Baffin Island, a generally broad continental shelf on the east, along Greenland, and a narrower shelf to the west bordering Baffin Island. Figure 4-32 (adapted from Muench) shows the major details of the bathymetry of the Baffin Bay region.

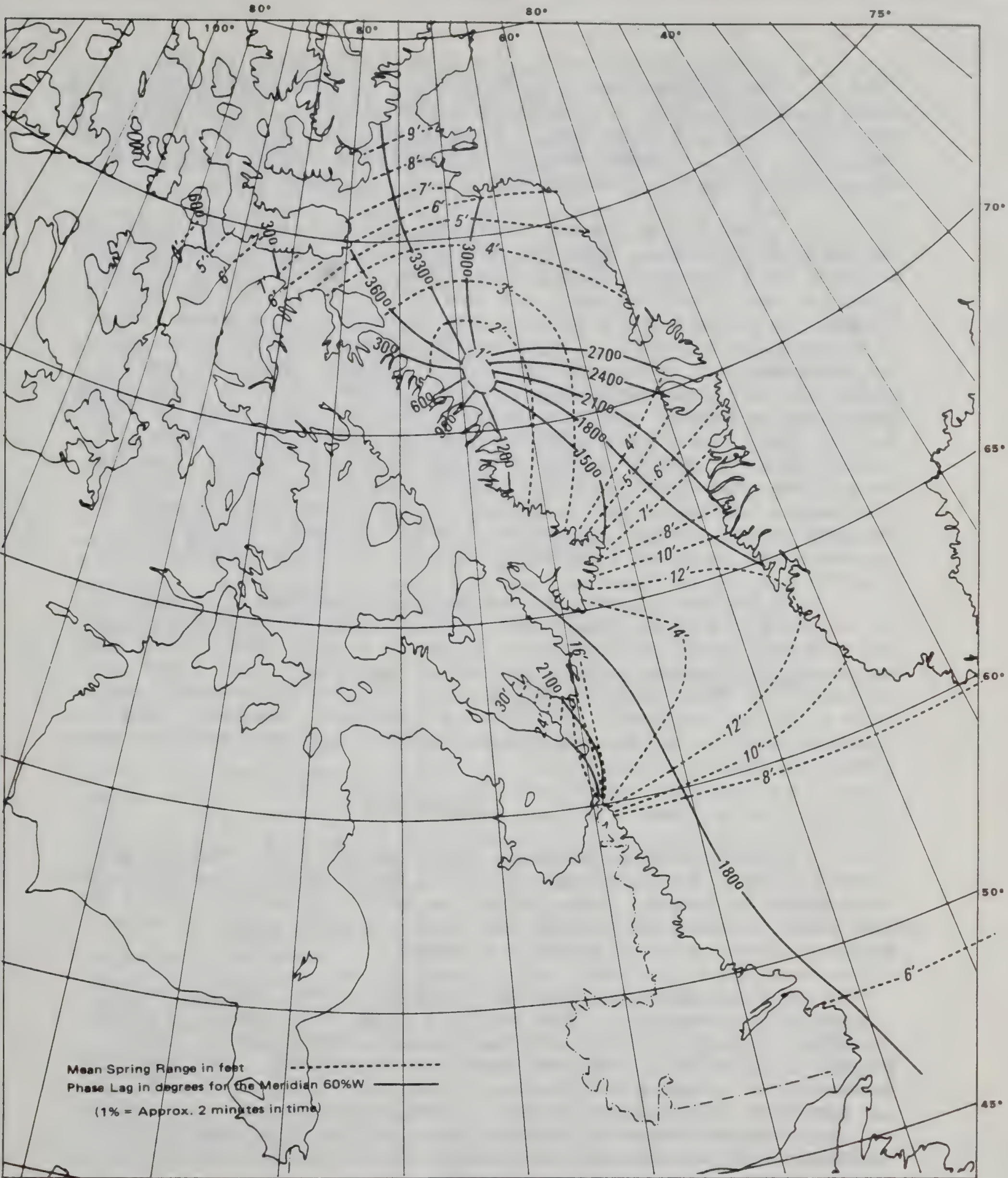


Figure 4-37

Tidal ranges of the Baffin Bay Region. (From Dohler, 1966)

The central basin has a maximum depth of over 2300 m. The depth over the Greenland continental shelf is as much as 400 m while the much narrower Baffin Island shelf is generally about 100 m deep. Baffin Bay is separated from the waters of the Labrador Sea by a submarine ridge rising to about 600 m depth in Davis Strait in latitude 65°.

The 600 m isobath crosses Lancaster Sound just west of Admiralty Inlet. One can conceptually regard the eastern portion of Lancaster Sound therefore as being in full communication with Baffin Bay. If the 600 m criterion is applied to the northern end of Baffin Bay however, then Smith Sound is virtually cut off. In terms of ocean current dynamics it is probably the slope of the bottom rather than the depth which is the more important factor in determining boundaries. The tightly packed contour lines are very prominent in Figure 4-32. The toes of the continental slopes of Greenland and Baffin Island are at about 1500 m, while the slope running east from Cape Dyer in Davis Strait rises from the 1200 m contour. In the northern end of the system such clearly defined steep slopes are absent but a marked steepening is apparent in Lancaster Sound just west of Admiralty Inlet.

One would expect the bottom topography to have a relatively stronger influence upon circulation in a weakly stratified, high latitude sea than in a well stratified sea in lower latitudes. We shall refer later to this important effect. In this review the details of the slope-shelf structure will be omitted. Of primary interest, however, are the contorsions of the continental slopes which are readily apparent in Figure 4-32.

4.1.7.3.2 Water Masses

Baffin Bay has been compared with the Norwegian - Greenland Sea by Sverdrup, et al, (1942) where a very similar situation is found, i.e., cold low salinity arctic water to the west flowing southward and warm, saline water of Atlantic origin to the east flowing northward.

The water masses of the Baffin Bay region vary greatly in character. The eastern side is strongly influenced by waters of the East Greenland Current which have mixed with Atlantic waters south of Greenland. The modified mixture is transported to the north along the Greenland Coast as the West Greenland Current. The character of the waters of the western side of Baffin Bay, on the other hand, is strongly influenced by the outflow from the Arctic Basin via Smith, Jones and Lancaster Sounds.

With this space scale and the size of the region in mind, the array of current meter moorings shown in Figure 4-38 was deployed. Forty-two current meters at 14 locations were moored at standard depths of 35, 125, 250, 500 and 750 m. The current meter deployments began in early August and the recoveries and re-deployments for the winter were completed by early October. Figure 4-39 shows the operational period for each of the current meters. In addition to measuring current speed and direction, the meters were equipped with conductivity, temperature and pressure sensors.

The analysis of the current data is not yet complete, however, preliminary analysis (Fissel, Lemon and Wilton, 1978) is available. The current at 35 m flows south westward off Devon Island toward Lancaster Sound. On the north side of Lancaster Sound the average velocity is over 50 cm s^{-1} to the west and generally more steady than in the other location. Off the north coast of Bylot Island, the current flows eastward with average speeds of 25 to 50 cm s^{-1}. The current off Cape Liverpool (the extreme northeastern point on Bylot Island) is quite variable and occasionally reverses, and flows westward. Further south along the coast of Baffin Island the average velocity is southward at 10-15 cm s^{-1}. The current records obtained in 1978 are described in more detail in Fissel *et al.*, (1978).

4.1.7.4.2 Lagrangian Current Measurements

If instead of observing the currents at a fixed point in speed, one observes the motions of a particular water parcel, the observations are termed Lagrangian. Such data do not readily lend themselves to time-series analysis but are well suited to sampling the trajectories of parcels of fluid. In particular, such measurements are very useful in predicting the motions of icebergs and oil slicks.

Three methods were employed which can be considered Lagrangian methods: icebergs, near surface drogues and oil spill followers were tracked. The first two platforms utilized RAMS satellite tracked buoys and the third type of platform - the oil spill follower was tracked from a ship. Preliminary results are available in Fissel *et al.*, (1978) however here we can say that while the drift paths from the first two types of platforms are rather jagged, their general tendencies are to follow the near surface ocean current. Fifteen RAMS buoys were deployed while two observation periods of the motions of oil spill followers were undertaken.

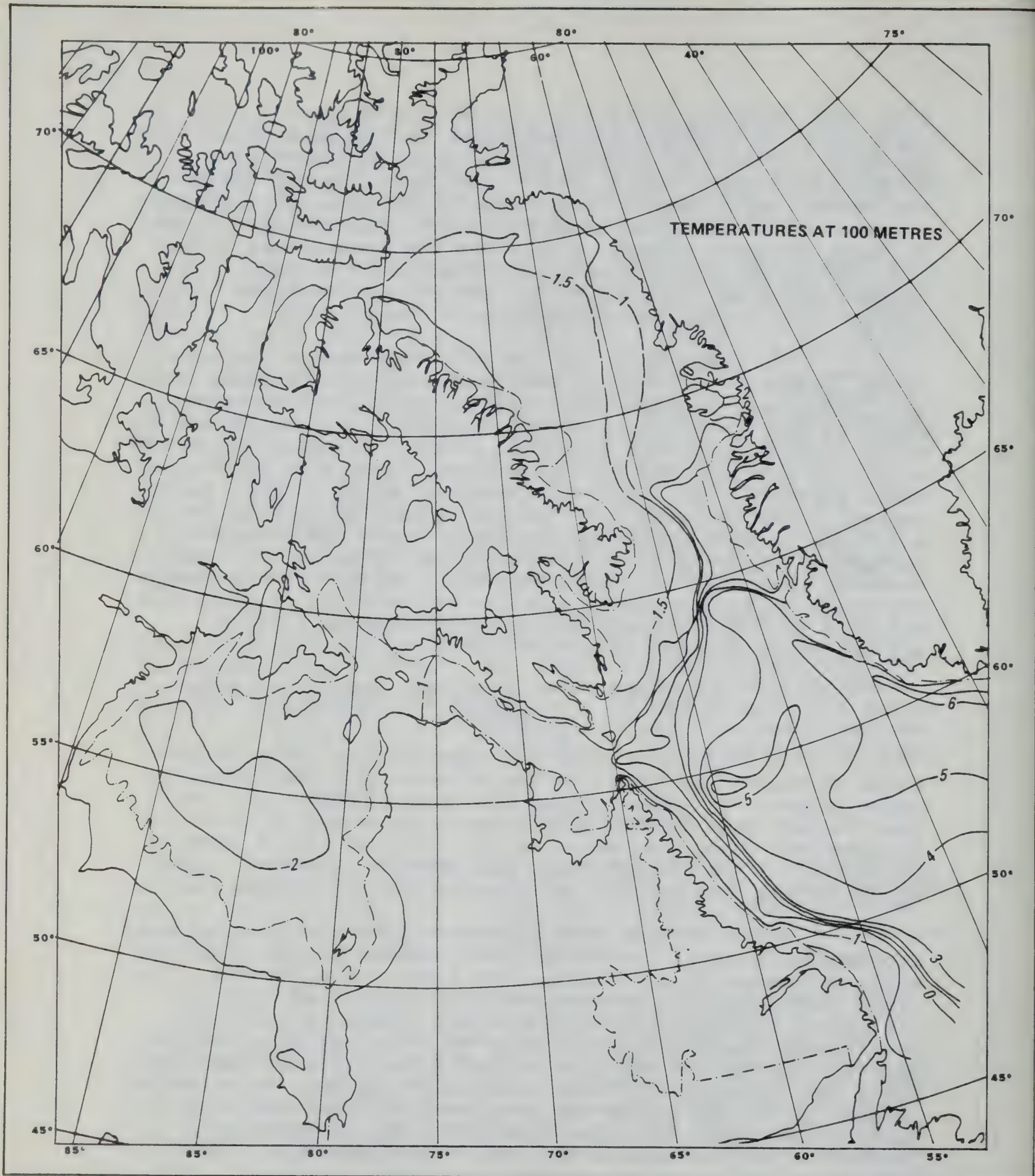


Figure 4–34 Temperatures at 100 metres, in degrees Centigrade, August-September, Composite figure from various sources. The -2^{O}isotherm in Hudson bay is based on the "Loubyrne" 1930 observations, which may no longer apply today. (From Dunbar, 1951)

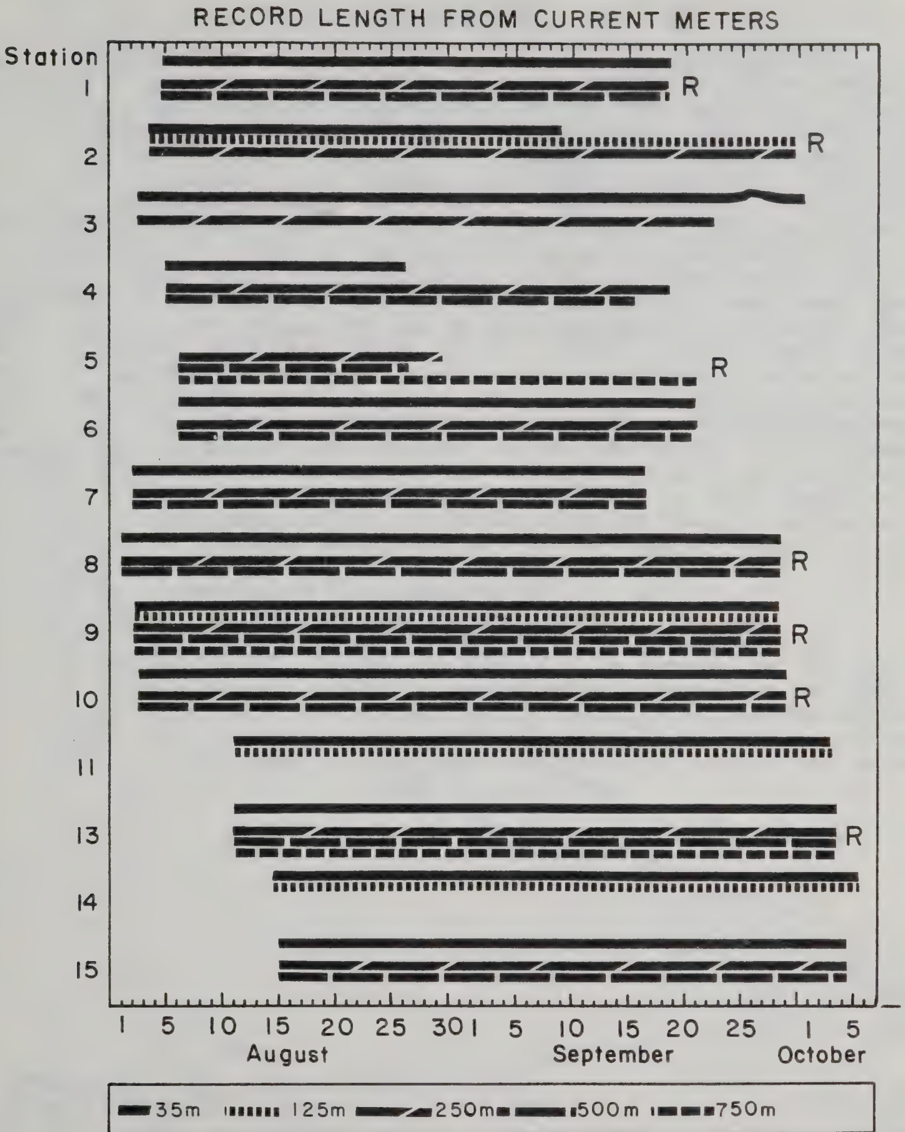


Figure 4-39: Operational period of each current meter. The symbol "R" signifies those moorings which were redeployed for the autumn 1978 to summer 1979 period.

4.1.7.4.3 Hydrographic Stations

Conductivity-Temperature-Depth data were collected at 84 stations during 1978. A total of 194 CTD costs were performed. The locations of the hydrographic stations are shown in Figure 4-40. The CTD data will be used to determine the horizontal field of temperature and salinity from which one can infer the sense of the larger scale fluid motions. The CTD data will also be used to construct dynamic topographies which indicate the geostrophic shear between chosen levels (the difference in speed between two depths). This data will also be employed in the computation of sound velocities - important information where the use of sonar is planned. Some preliminary results of the CTD survey too, appear in Fissel et al, (1978). It is hoped that this, the densest suite of temperature and salinity data yet collected in this region will add considerably to the understanding of the marine environment off the coast of Baffin Island. In conjunction with the occupation of hydrographic stations, vertical profile of current speed and direction were obtained over the upper 50 m of the water column. The data from the profile are to be used to extrapolate the information from the moored current meters at 35 m depth to the surface.

4.1.7.4.4 Tide Gauges

Two internally recording water level gauges were installed at two locations in Lancaster Sound. These instruments will be recovered in the summer of 1979. The data will add to the knowledge of the propogation of tidal energy in the region as well as help to elucidate the nature of the longer period (10-15 day) oscillations already observed.

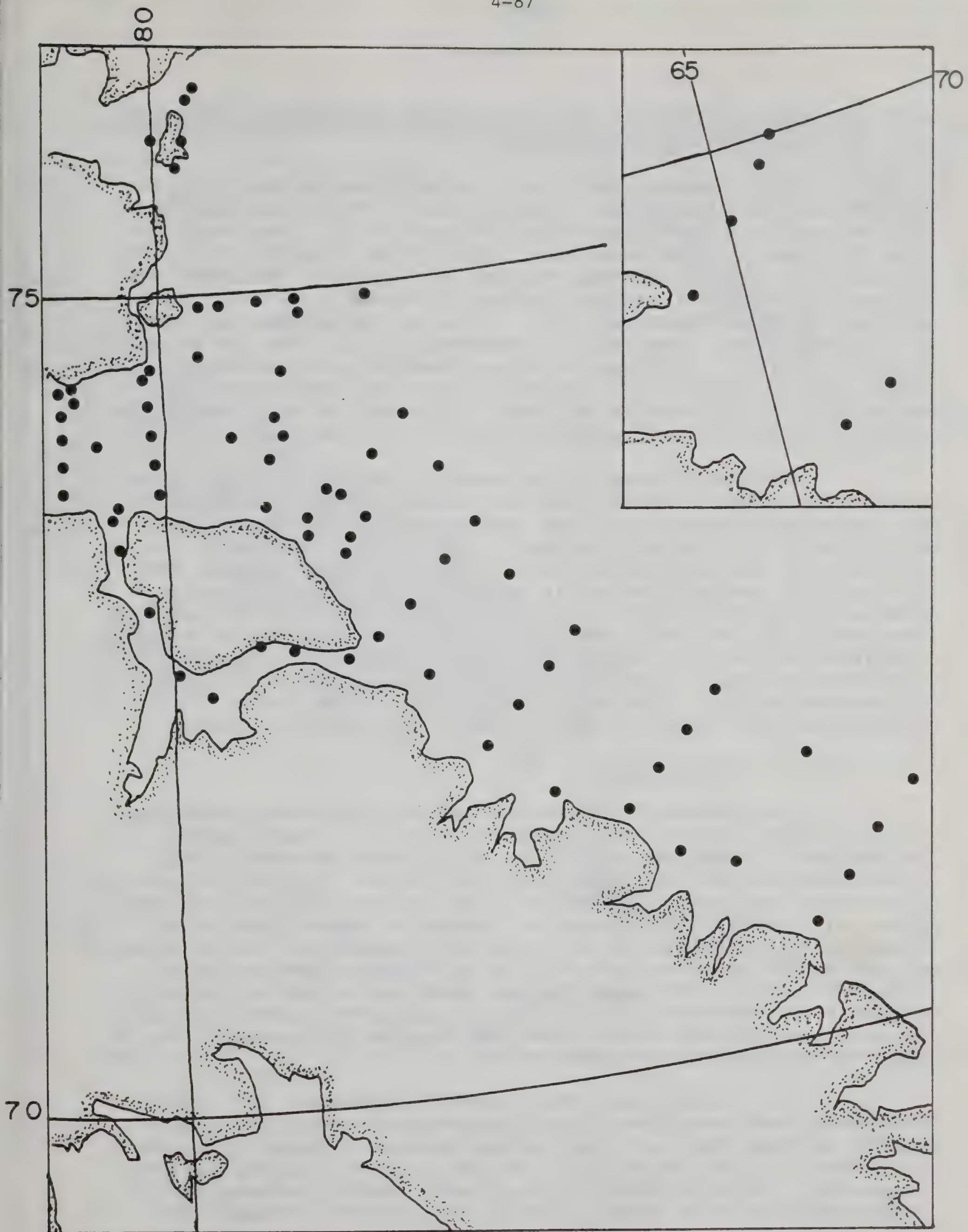


Figure 4-40: Location of hydrographic stations.

4.2 EXISTING BIOLOGICAL ENVIRONMENT OF NORTHWEST BAFFIN BAY AND EASTERN LANCASTER SOUND

This chapter provides a brief general description of the existing biological environment of northwest Baffin Bay and eastern Lancaster Sound (Figure 4-41). The description is based on published and unpublished literature but it relies most heavily on the studies conducted by Norlands Petroleums Limited in eastern Lancaster Sound in October 1975 and May through September 1976. A major environmental program (EAMES) was conducted in northwest Baffin Bay by Petro-Canada in 1978. Outlines of these studies are presented in a later section (4.2.10). However, since few results and no reports of these studies are yet available, this document includes little new information from the 1978 studies.

Species diversity is lower in arctic than in temperate or tropical waters, but the number of species present in the Arctic ranges into the thousands and new species are still being discovered (Lubinsky, 1976). The following description of the biological characteristics of northwest Baffin Bay and eastern Lancaster Sound is not intended to be a complete and exhaustive literature review of all organisms in the area. In general, lower trophic levels (phytoplankton, zooplankton, benthic algae, etc.) are treated more generally than vertebrates. Seabirds and marine mammals are discussed in greater detail. Emphasis is also placed on trophic relationships, especially as they affect important vertebrates.

4.2.1 Microbiota

"Microbiota" is a term used to denote an assemblage of very small plants and animals (bacteria, yeasts, molds, protozoans, nematodes, etc.) or, in an even broader sense, all organisms that are microscopic in size. In the present discussion the terms "microbiota" or "microorganism" are applied with special reference to bacteria, yeasts and molds. Interest in these groups is especially warranted, since some of the organisms have the ability to degrade hydrocarbons (Karrick, 1977). No research has been performed on the microbiota of northwest Baffin Bay or Lancaster Sound, but due to their ubiquitous nature some applicable information can be drawn from research in other areas.

Two broad categories of microorganisms are autotrophs and heterotrophs. The former group resembles green plants in that they utilize carbon dioxide, simple inorganic salts and in some cases light to manufacture complex organic compounds. Heterotrophs, in contrast, break down organic compounds for their energy and in the process release inor-

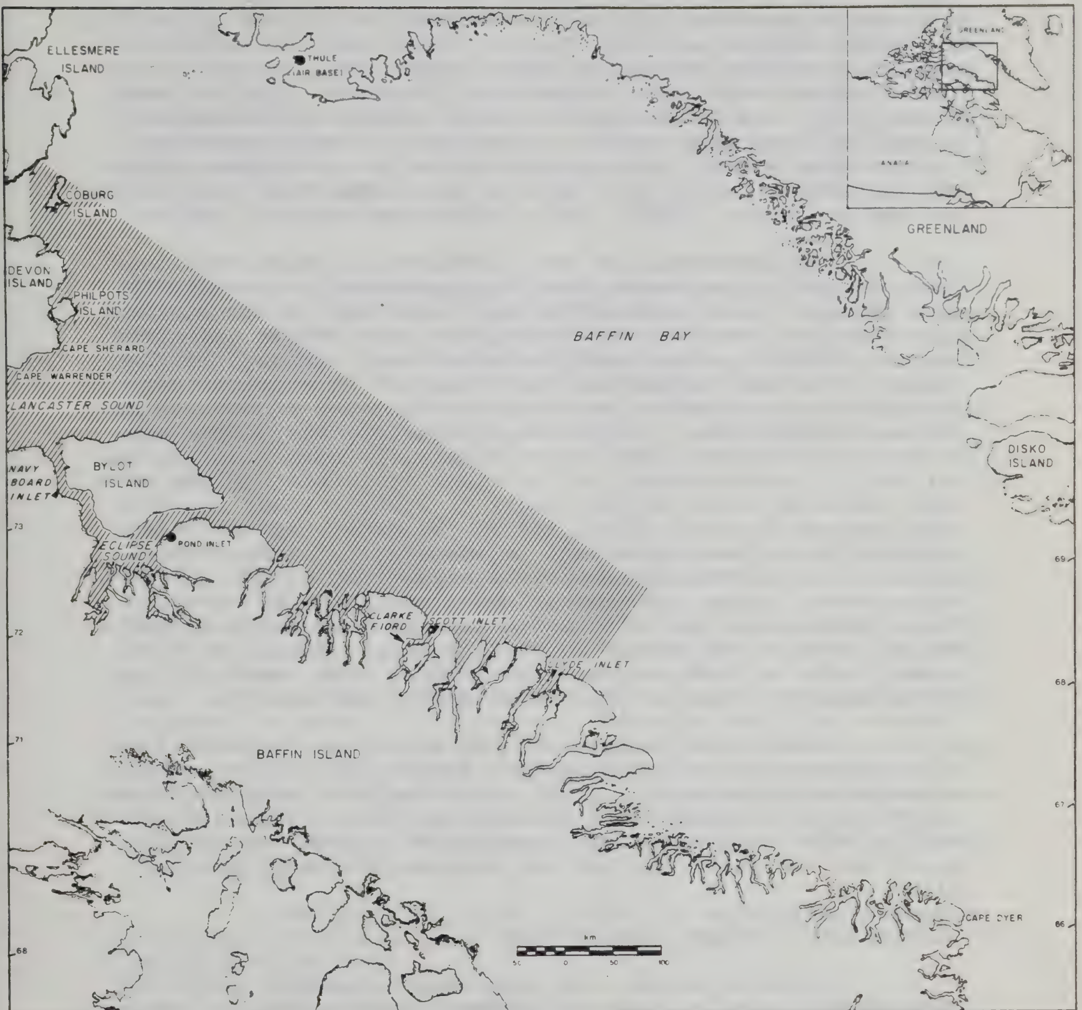


Figure 4-41
Study Area in Northwest Baffin Bay and Eastern Lancaster Sound, 1978.

ganics, some of which are plant nutrients. In the sea, heterotrophic microbiota are of extreme importance since they are ultimately responsible for the transformation of all organic matter into inorganic forms, which are, in turn, recycled by plants and other microbiota (Sverdrup et al., 1942; Kriss et al., 1967; Sieburth, 1976). Heterotrophs appear to be universal in the marine environment. Recent investigations in the Arctic have confirmed that heterotrophs inhabit sea ice (Alexander et al., 1974), as well as the water column and the sediments (Bunch, 1974; Bunch and Harland, 1976).

The distribution of oleoclasts (heterotrophs that have the ability to break down hydrocarbons) in the sea is also thought to be extremely broad. Karrick (1977) implied that specific searches for oleoclasts need not be performed because of their widespread distribution. Although little research has been performed in the Arctic it appears that oleoclasts are found in small numbers in most if not all major marine habitats. In the south Beaufort Sea, Bunch and Harland (1976) found them to be relatively common in the water and in nearshore but not offshore sediments. Oleoclasts were found in water and sediments at Frobisher Bay (Mulkins-Phillips and Stewart, 1974) and in the water, sediments and ice near Point Barrow, Alaska (Atlas et al., 1978). Abundance of oleoclasts appears to be a function of the amount of hydrocarbon in the environment and time (Karrick, 1977). Thus, chronically polluted areas such as many southern ports and industrialized bays support very large numbers of oleoclasts. It is thus not expected to find that low densities of oleoclasts occur in unpolluted Arctic waters.

While the presence of oleoclasts in the arctic marine environment can be expected, little information exists on rates of degradation of oil and effects of temperature and other physical factors on degradation rates. Recent research implies that complete biodegradation of oil in the Arctic would require years and perhaps decades (Atlas et al., 1978).

4.2.2 Plant Communities

Benthic algae, ice-associated (epontic) algae and phytoplankton are present in northwest Baffin Bay and eastern Lancaster Sound. Of these three groups, the phytoplankton is by far the best known.

4.2.2.1 Benthic Algae

Benthic algae range in size from microscopic forms (primarily diatoms) to species that are several metres in

length; the latter are commonly called seaweeds, kelp or macrophytes. As in most other regions of arctic Canada, the distribution and abundance of macrophytes in the study area are unknown. Lee (1973) and Wilce (1973) have summarized some aspects of the general ecology of benthic algae (primarily macrophytes) in the Arctic. Their observations are, in all probability, also applicable to Lancaster Sound and northwest Baffin Bay and much of the following general discussion is from their work.

Only about 150 species of macrophytes, of which over 99% are also found in the North Atlantic, occur along the shores of West Greenland and Baffin, Devon and Ellesmere Islands. Annual species predominate in the littoral and upper sublittoral zones. Below depths of 4 to 6 metres, perennial macrophytes are most common. Maximal development of most macrophytes occurs at greater depths in the Arctic than in southern waters. Most grow below 10 metre depths and a substantial number of species is found in depths from 30 to 70 metres.

The nature of arctic benthic algal communities changes dramatically between high tide levels and 100 metre depths. Distinct communities grow in bands or zones that are subjected to different physical factors (e.g., waves, currents, salinity, light, ice scour). Such zones in the Arctic have been described by Wilce (1973) and are shown in Figure 4-42. Fewer than 50 species of algae (most of which are small annuals) are found in the High Arctic littoral zone as compared to about 150 species in Canadian Maritime waters. The impoverished state of this community has been attributed to ice scour and extreme fluctuations in temperature and salinity (Lee, 1973; Wilce, 1973). The few perennial species that do survive in the littoral zone, such as _Fucus distichus_, are dwarfed and grow in protected rock crevices and sheltered depressions.

Arctic sublittoral vegetation appears as a broken and unpredictable belt of vegetation - possibly a function of unstable substrate.

Extending to one or two metres below low water is the sublittoral _Barren Zone_. The uniform barrenness of this area makes it a characteristic feature of coasts throughout the arctic archipelago. Continual ice scouring and salinity fluctuations are major life-inhibiting factos. In contrast, in Canadian Maritime regions, the first metre of the sublittoral zone is often the most populated.

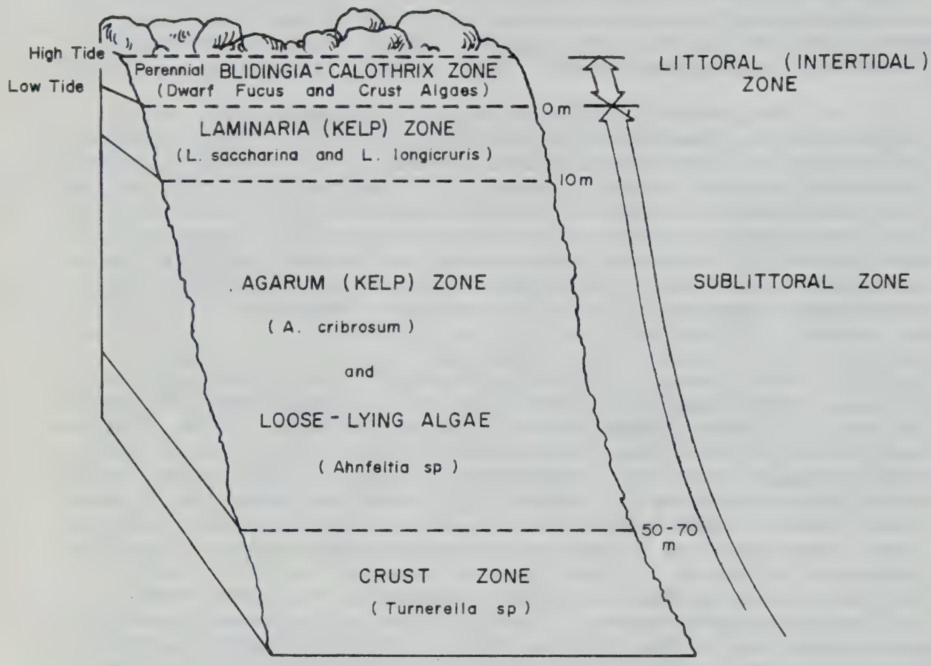


Figure 4-42

Zonation Patterns of Arctic Macrophtyes on Rocky Substrate (from Wilce, 1973).

The first heavily vegetated zone in the arctic sublittoral is called the Laminaria Zone. Three kelps, *Laminaria saccharina*, *L. longicruris* and *Agarum cribrosum*, are characteristic plants of this zone. In North Atlantic waters, the Laminaria Zone provides the bulk of seaweed biomass. In the Arctic, this zone is discontinuous and patchy and sometimes absent, possibly from causes such as a scarcity of nutrients, lack of suitable substrates, low illumination and low salinity waters (Wilce, 1973).

The Agarum Zone (named after the dominant kelp *A. cribrosum*) extends downward from about 10 to 50 or 70 metres. About 48 species have been found in this zone. Except for seasonal light fluctuations, physical factors within this zone are more stable than within the Laminaria Zone. A feature of the arctic Agarum Zone is the presence of loose-lying algae, most often encountered along moderately exposed coasts, deep bays and fjords. These populations of single or mixed species grow unattached to the sea bottom but are, nevertheless, permanent residents. They simply require shelter from strong currents and the type of substrate is not critical. These beds of unattached plants can be extensive, up to 50 metres square and 1 metre thick.

The Crust Zone is the region of arctic sea bottom below 50-70 metres, where only the hardiest crust algae and upright species can survive. Although water at these depths provides the most stable physical environment, low illumination generally limits plant growth.

Although all the results of the 1978 studies in and near Baffin Bay for Petro-Canada are not available at the present time, general findings suggest that typical arctic macrophyte communities were present in all areas studied. It should be emphasized that the above description of macrophyte distribution only applies to locations where substrates include large, rocky areas (e.g., large cobbles, boulders, bedrock). Regions of gravel, silt or mud are unstable and unsuitable for attachment of macrophytes. In addition, although macrophytes generally occur in all large rocky areas, it is not yet possible to predict the microdistribution of macrophytes. Macrophyte beds are discontinuously distributed over large regions of apparently suitable substrate.

4.2.2.2 Phytoplankton

Due to the three-dimensional nature of phytoplankton distribution, they contribute most to total primary production and they are of great importance in determining the biological characteristics of an area. Phytoplankton form

the base of the food chain for herbivorous zooplankton (some of which are eaten directly by some birds and marine mammals) and they also contribute organic detritus that is procesed in detrital cycles either in the water column or on the sea bottom.

4.2.2.2.1 Abundance and Distribution

The abundance and distribution of phytoplankton in the upper 50 metres of Lancaster Sound were measured by Sekerak et al. (1976b) from late July to mid-September, 1976. Unreplicated data were obtained for each combination of six stations, four depths (0-50 m) and five periods (July-Sept. 1976) (Figure 4-43). Although their findings show great variability by depth, area and season, several trends permit certain generalizations. The following description relies heavily on their findings, since the results of research sponsored by Petro-Canada in 1978 are not yet available.

Three-quarters of the 125 recorded species of phytoplankton in Lancaster Sound were diatoms; the remainder were chrysophytes (14%), microflagellates (9%), and dinoflagellates (2%), with negligible numbers of chlorophytes. This composition is typically arctic. The number of phytoplankton species recovered from Lancaster Sound (125) compares closely with that from Foxe Basin (121 species; Bursa, 1961b) but contrasts with more diverse areas such as Hudson Bay and James Bay (over 200 species; Bursa, 1961a; Foy and Hsiao, 1976) or regions of low diversity such as the Beaufort Sea (87 species; Hsiao, 1976).

A single species of diatom, Chaetoceros socialis, accounted for over 50% of the total number of phytoplankton found in Lancaster Sound during the sampling period in 1976. When sampling was initiated in late July large concentrations (over 100 x 10^5 cells/litre) were common. It is not known when this bloom commenced but numbers of C. socialis decreased substantially after mid-August. Despite its small size, C. socialis was a large contributor to phytoplankton biomass. The most important species of the phytoplankton community in Lancaster Sound and their abundance are listed in Table 4-4. All are typical arctic species.

Total standing crop in Lancaster Sound in the summer of 1976 was substantially less at 50 m depth than at shallower depths, and decreased after early August. The temporal decline was in large part due to reduced numbers of a single species, Chaeteceros socialis. C. socialis was significantly more abundant at Cape Warrender and the eastern

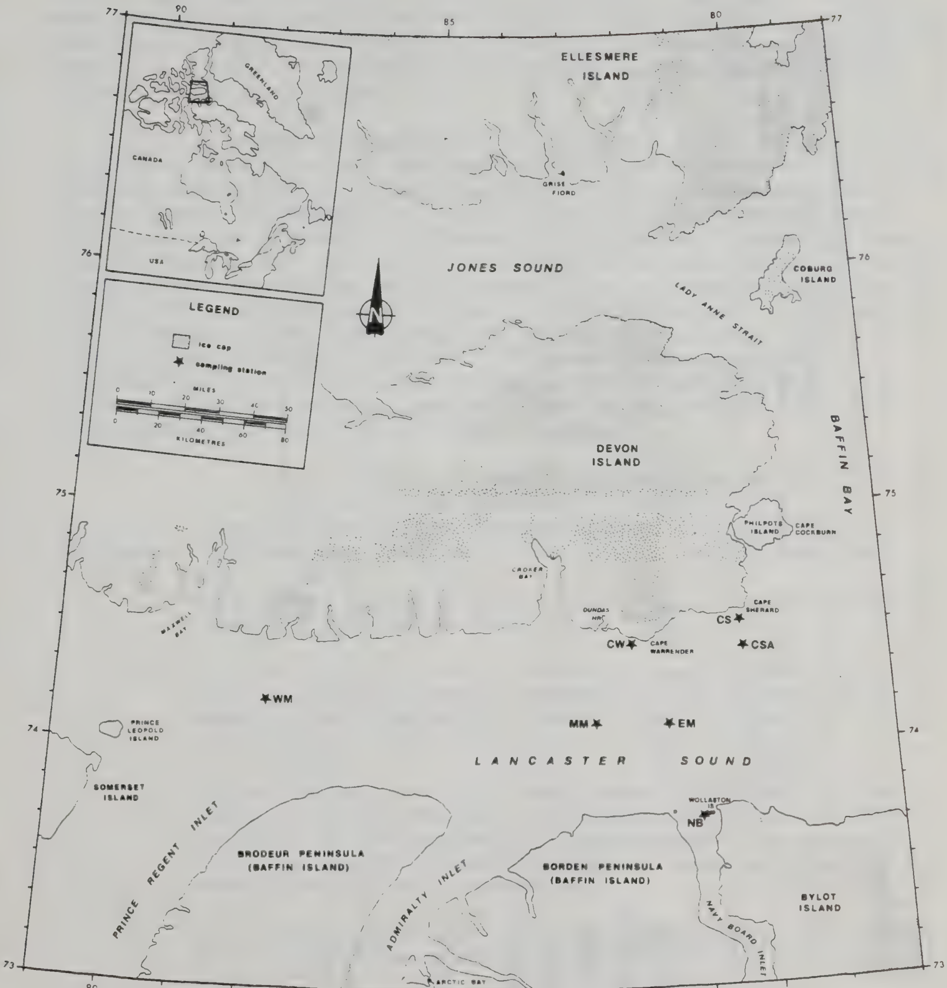


Figure 4-43
Biological Sampling Sites in Lancaster Sound, 1976.

Table 4-4:
Average Abundance (TCC* x $10^4/\ell$) of The Eight Most Common Species of Phytoplankton in Lancaster Sound (from Sekerak *et al.*, 1976b).

Species	Location						Mean
	Cape Warrender	Cape Sherard	East mid-Lancaster Sound	Middle mid-Lancaster Sound	Navy Board Inlet	West mid-Lancaster Sound	
Diatoms							
Chaetoceros socialis	286	126	225	134	48	73	149
Fragilariopsis oceanica	13	4	3	7	27	36	15
Thalassiosira gravida	5	3	1	3	2	2	3
Chaetoceros compressus	1	<1	<1	<1	1	<1	<1
Thalassiosira nordenskioeldii	2	3	1	1	4	3	2
Nitzschia seriata	3	<1	2	2	4	3	2
Leptocylindrus danicus	1	<1	1	<1	<1	<1	<1
Chrysophytes							
Dinobryon balticum	20	19	19	9	23	10	17
All Species	349	168	266	168	110	147	201

* Total Cell Count.

mid-channel station than at the westernmost station and at Navy Board Inlet (Sekerak et al., 1976b). Although tentative, this suggests that basic differences may exist between western and eastern Lancaster Sound. Such differences may be due to differences in origin of waters and water circulation patterns within the sound or different replenishment mechanisms for plant nutrients.

A common method used to estimate plant biomass or "standing crop" is the measurement of plant pigments, in particular chlorophyll a concentrations. This technique has limitations, rendering chlorophyll a data most useful for comparing the general "richness" of different seas. In Lancaster Sound, the surface waters exhibited an average chlorophyll a concentration of 1.23 mg/m^3, but ranged as high as 5.16 mg/m^3. Figure 4-44 shows a close relationship between phytoplankton standing crop and estimated biomass (using plant pigment concentration). Average concentrations of chlorophyll a were highest at depths of 25 metres and to a lesser extent 10 metres, perhaps indicating greatest photosynthetic activity at these depths.

4.2.2.2.2 Regional Comparisons

Comparisons of the phytoplankton communities in different regions are difficult for the following reasons:

1. Population dynamics of different species vary dramatically with season.

2. At least two distinct communities exist in the Arctic: a spring - early summer "shade" flora and a summer "sun" community (Bursa, 1961b; Raymont, 1963; Bain et al., 1977).

3. Phytoplankton are not distributed uniformly in the water column. Patches of phytoplankton can exist on a micro- (a few metres) or macro-scale (several km). For this reason a small number of samples may yield unrepresentative information.

4. Total cell counts and species identifications depend on the expertise and thoroughness of the taxonomist.

5. Measurements of chlorophyll a overcome (4) but concentrations of chlorophyll a vary among species and with the physiological state of individuals as well as with (1) to (3) above.

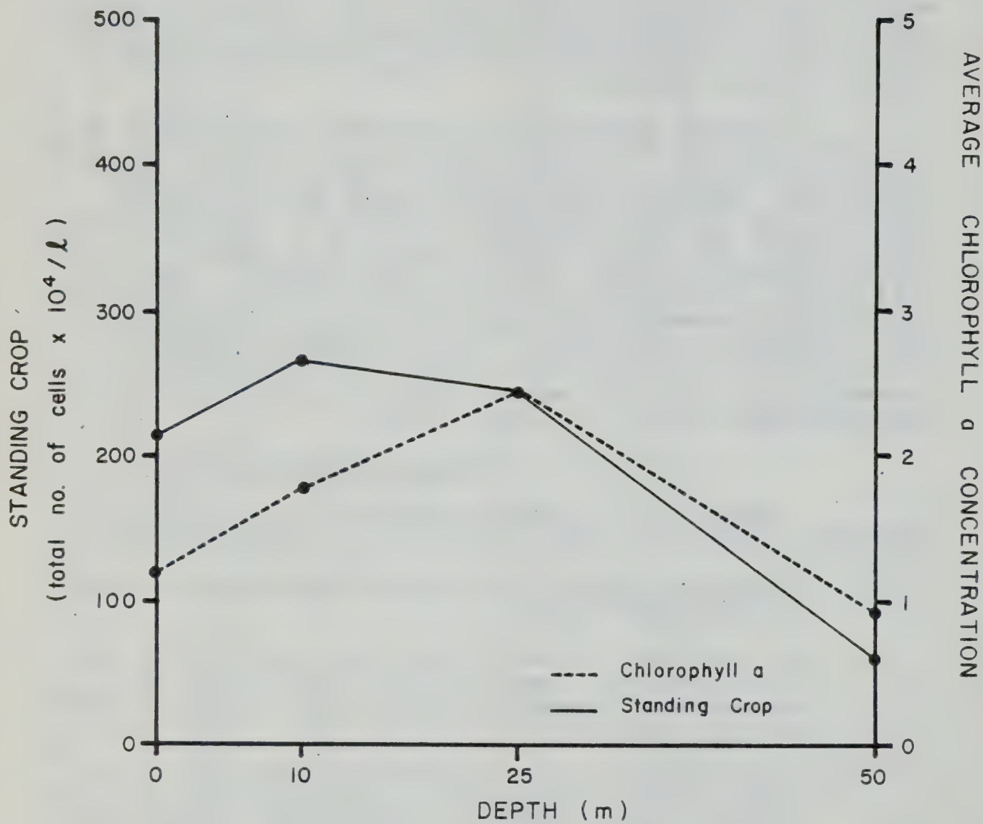


Figure 4-44:

Comparison of Average Standing Crop (expressed as total cell counts) and Average Chlorophyll *a* Concentrations for each Sampling Period (from Sekerak *et al.*, 1976b).

6. Few intensive studies have been performed in the Canadian Arctic.

It is probable that the sampling period in Lancaster Sound during 1976 spanned the time of maximal development of the summer or "sun" phytoplankton community; therefore, the data on phytoplankton in Lancaster Sound should be compared only to the summer communities of other regions. Of the results listed in Table 4-5 those of Bursa (1961a, 1971) are the most comparable to data from Lancaster Sound with respect to sampling intensity. Data from the remaining studies were based on small numbers of samples. It can be seen that phytoplankton were very abundant in Lancaster Sound in the summer of 1976. Mean cell counts in Lancaster Sound and at Frobisher Bay were roughly double those found in the next highest area, Assistance Bay; occasional single samples from other regions (e.g. Viscount Melville Sound) exceeded the maxima found in Lancaster Sound and Frobisher Bay. Chlorophyll a concentrations were quite similar at Lancaster Sound and the next highest site, Assistance Bay, Cornwallis Island.

Reasons for the large densities of phytoplankton in Lancaster Sound are unknown, and it is difficult to place Lancaster Sound in a regional context due to lack of baseline data from other areas, especially areas that are physically similar. Factors that produce large standing crops of phytoplankton in eastern Lancaster Sound may not be widespread throughout the Arctic or even northwest Baffin Bay. For example, although water current patterns in Lancaster Sound are not precisely known, sufficient data exist to indicate that counter-currents and gyres are present at the eastern entrance. If such currents bring plant nutrients to surface waters in summer, primary production would be substantially increased and the area would be quite unusual in comparison to other arctic regions. However, it is not necessarily unique. Similar current patterns and physical processes might occur at the mouth of Jones Sound and perhaps the eastern entrance of Hudson Strait, portions of the eastern Arctic for which comparative data are unavailable. Data collected for Petro-Canada in 1978 in NW Baffin Bay should, when available, be useful in addressing some of these questions.

4.2.2.3 The Epontic Community

Both ice-associated plants and animals are discussed in this section since it is apparent that they are closely interrelated and that the community may function as a more or less self-contained unit for at least part of the year. This community has not been studied in Baffin Bay or

Table 4-5:
Phytoplankton Standing Crop in Lancaster Sound and other Arctic Waters (modified from Sekerak *et al.*, 1976b).

Area	Sampling Period	Depth Sampled (m)	Nos./m^3 Average	Nos./m^3 Maximum	Biomass (mg/m^3) Average	Biomass (mg/m^3) Maximum	Dominant Species (numbers) in Area Excluding Larvaceans	Reference
Lancaster Sound	July-September	0 to 150	1356	3733	247	696	*Pseudocalanus minutus*	Sekerak *et al.*, 1976b
Cape Warrender			1286	2571	340	696		
Cape Sherard			746	1459	246	406		
East Mid-Sound			652	1516	181	306		
Middle Mid-Sound			1304	1850	284	446		
Navy Board Inlet			2483	3733	263	612		
West Mid-Sound			1306	2038	171	293		
Foxe Basin	June-October						*Pseudocalanus minutus*	Grainger, 1962
East		0 to 50	-	-	29	57		
West		0 to 50	-	-	61	108		
Southwest		0 to 100	-	-	56	93		
Assistance Bay, Cornwallis Island	July-August	Various depths between 0 and 50	3405	11,577	80	107	*Pseudocalanus minutus*	Mohammed and Grainger, 1974*
Slidre Fjord, Ellesmere Island	July-August	0 to 50	477	719	82	139	*Pseudocalanus minutus*	Mohammed and Grainger, 1974*
Creswell Bay, Somerset Island	July-August	0 to 40	607	1611	193	351	*Pseudocalanus minutus*	Mohammed and Grainger, 1974*
Bridport Inlet, Melville Island	August	0 to 25	184	461	119	167	*Oithona similis*	Buchanan *et al.*, 1977
		25 to 50	654	954	188	128		
		0 to 50	237 (single sample)		84 (single sample)			
		120 to 50	24 (single sample)		13 (single sample)			
Viscount Melville Sound, near Bridport Inlet	August	0 to 25	233 (single sample)		15 (single sample)		*Oithona similis*	Buchanan *et al.*, 1977
		0 to 50	385 (single sample)		78 (single sample)			

* Technical report of raw data from which above information was calculated.

Lancaster Sound nor has it been intensively studied in any area of the Canadian Arctic. Most of the following material is, therefore, based on the scanty information that exists for other arctic regions, which was summarized by Horner (1977). It should be noted, however, that most studies and observations have been made under landfast, unmoving ice. Most of the ice in eastern Lancaster Sound and Baffin Bay is unconsolidated and it is not known if such ice has similar biological characteristics.

Sufficient research has been performed to firmly establish that a well-developed community of plants and animals lives in, on or near the undersurface of sea ice. This community has been referred to as "ice biota" or the "epontic community". Of significance is that ice algae or "ice flora" contribute to the primary production of marine waters and also form a concentrated food supply for herbivorous invertebrates; these animals are fed upon by larger invertebrates and fish and they are in turn eaten by seabirds and some marine mammals. Therefore, the ice flora forms the base of a food web that ultimately supports many of the higher trophic levels in the Arctic. Although the absolute or relative importance of the ice biota as a whole has not been clearly established it is evident that many valued animals utilize specific components of the system. For the above reasons the epontic community is described in some reasonable detail below.

4.2.2.3.1 Epontic Algae

Microscopic algae (primarily pennate diatoms) have been known for some time to live in or on the undersurface of sea ice (Ehrenberg, 1841, 1853). However, it has only been within the last few decades that notable advances in knowledge have been made. Recent research has documented ice communities of epontic algae in the Antarctic (Bunt, 1963, 1964) and Arctic: Beaufort Sea (Alexander et al., 1974), Jones Sound (Apollonio, 1965), Frobisher Bay (Grainger, 1971) Austin Channel and Barrow Strait (Thomson et al., 1975), Resolute Bay and vicinity (Welch and Kalff, 1975), Bridport Inlet along Melville Island (Buchanan et al., 1977) and Allen Bay, Cornwallis Island; Brentford Bay, Boothia Peninsula; and Aston Bay, Somerset Island (LGL Ltd., unpubl. data). These studies have proved conclusively that a widespread feature of sea ice is the development of a community of plants (and animals) in or on its undersurface, especially in late winter and spring. While this advance is noteworthy, factors affecting the function of this community and its significance to arctic marine systems remain largely unknown. Rates of primary production of ice algae have rarely been successfully

measured. Alexander (1974) estimated that up to 5 g $C/m^2/yr$ were fixed by epontic algae in nearshore regions of the Beaufort Sea off Alaska. Welch and Kaff (1975) suggested that production by epontic algae in offshore areas of Barrow Strait was equivalent to production by benthic plants in Resolute Bay (approximately 16 g $C/m^2/yr$). Present knowledge indicates that epontic algae definitely have importance in the primary production processes of arctic waters.

Of perhaps greater significance than their contribution toward primary production is the timing of the maximum development of epontic algae and the location of the commmunity. While traces of algae can be found throughout the ice during the entire "ice year" (Thomson et al., 1975), the community blooms in spring, generally from late April to early June. At this time, dense mats of algae occur on the lowermost portion of the ice surface. Dunbar (1968) suggested that the timing of the epontic bloom could be very significant since it occurs well in advance of the spring bloom of phytoplankton. Hence, epontic algae form a concentrated food supply for herbivorous animals at a time when other sources of food appear to be in short supply. For example, Thomson et al. (1975) found that, on a per volume basis, algae in the lowermost portion of the ice in West Barrow Strait in early May were about 160 times more abundant than in the water column beneath the ice.

4.2.2.3.2 Additional Lower Trophic Levels

Protozoans, nematodes, turbellarians, polychaete larvae and a variety of heterotrophic microorganisms are common in samples from the lower-most surface of ice (Horner and Alexander, 1972; Thomson et al., 1975; Buchanan et al., 1977). The presence of this diversity of organisms within the ice indicates that a complex food web is established. As evidenced by the presence of heterotrophs, detritus may be utilized and nutrients could also be regenerated within the ice community.

4.2.2.3.3 Higher Trophic Levels

In addition to the microscopic plants and animals previously discussed, several species of copepods and amphipods are associated with sea ice. Copepods, both harpacticoids and cyclopoids, have been reported to be occasionally abundant in ice samples (Horner et al., 1974; Thomson et al., 1975). Buchanan et al. (1977) and Green and Steele (1975) reported that the amphipod *Gammaracanthus loricatus* was

commonly observed inside ice stalactites in June, although it was also observed in the water column.

Recent SCUBA observations in the Canadian Arctic have broadened our understanding of the types of animals that can be classified as sub-ice fauna or "ice-epifauna". Buchanan et al. (1977) reported a considerable number of amphipod species on or in extremely close proximity to the undersurface of ice in Bridport Inlet in June. Onisimus litoralis, O. glacialis and O. nanseni were most common but also present were Gammarus setosus, G. wilkitzkii, Gammaracanthus loricatus and Apherusa glacialis. A swarm of Onisimus litoralis with an estimated density of about 10,500/m^2 was observed, apparently feeding on the undersurface of the ice. Differences were also observed in the abundance of certain species at different locations, with O. litoralis and O. glacialis being most common at nearshore and offshore stations, respectively.

An important trophic link between the epontic community and higher vertebrates may be the arctic cod, Boreogadus saida. This species of fish is reported to be associated with ice for at least part of the year (Andriashev, 1954, 1970; McAllister, 1975), presumably feeding on ice-associated invertebrates. The arctic cod is one of the most abundant fish in the Arctic and, as will be discussed in Section 4.2.9, is of considerable importance in food chains leading to higher vertebrates. Little is known about the ecology of arctic cod in Canadian waters. In the Russian Arctic, cod have been reported to be associated with ice. Large concentrations of cod have been observed near the ice edge in the northern Kara Sea (Ponomarenko, 1968). The limited amount of information available on arctic cod in Canada is discussed in Section 4.2.5.

The above material concerns the importance and relationships of the epontic community in the spring when maximal development occurs. Some organisms also associate with ice in other seasons. Flagellates are common in new ice in the fall. The amphipods Apherusa glacialis and Onisimus glacialis occur in extremely large numbers under and along the edges of drifting pan ice in summer and fall (LGL Ltd., unpubl. data). Many other relationships are presumably yet to be discovered.

4.2.3 Zooplankton

Unlike phytoplankton, zooplankton are not limited in their depth distribution; they occur in relatively large numbers throughout the water column. Zooplankters are primarily herbivorous and they are instrumental in the conversion of plants (phytoplankton) into animal tissue. As such they have great importance in marine systems. Although a few particularly large species are consumed by ringed seals and seabirds and the bowhead whale feeds primarily on zooplankton, the majority of zooplankton species and individuals are small and are not fed upon directly by birds and mammals. Trophic relationships are further explained in section 4.2.9.

Apart from Sekerak et al. (1976b), references pertaining to zooplankton in the study area are of a distributional, nonquantitative nature and are mostly related to material collected during the Godthaab Expedition of 1928. (This expedition reached the eastern entrance of Lancaster Sound). The following descriptive material is, therefore, necessarily based on Sekerak et al. (1976b) and comparisons of zooplankton in Lancaster Sound with those in other regions. Results of zooplankton sampling in the northwest Baffin Bay area in 1978 are not yet available.

4.2.3.1. Abundance and Distribution

Approximately 64 species of zooplankton were recovered from the upper 150 metres of Lancaster Sound in 1976; however, only about 25 species were important in terms of numbers or biomass (Sekerak et al., 1976b). Important groups were copepods, pteropods, chaetognaths, amphipods, larvaceans and to a lesser extent medusae and ctenophores (Table 4-6.

Numbers of zooplankton varied considerably at particular locations, depths and periods in Lancaster Sound. Highest densities of animals occurred in Navy Board Inlet, especially in late July. This location was unusual in that large numbers of copepod nauplii (larvae) and larval pteropods were present and contributed substantial numbers toward density estimates until late August. Average densities were approximately equal at west mid-Lancaster Sound, Cape Warrender and middle mid-Lancaster Sound (1200 to 1300 animals/m^3), and lowest at Cape Sherard and east mid-Lancaster Sound (650 to 750 animals/m^3). Figure 4-43. shows the locations sampled by Sekerak et al. (1976b).

Table 4-6:
Distribution and Average Abundance (no./m^3) of Major Zooplankton Groups in the Upper 150 m of Lancaster Sound Waters, July 22 to September 13, 1976 (from Sekerak *et al.*, 1976b).

Major Group	Cape Warrender	Cape Sherard	East mid-Sound	Middle mid-Sound	Navy Board Inlet	West mid-Sound
Copepods	834	538	402	763	1471	827
Larvaceans	377	189	215	409	563	360
Pteropods	26	3	7	48	378	57
Ctenophores & Cnidaria	11	6	6	16	4	2
Chaetognaths	2	2	1	1	3	2
Amphipods	2	1	1	1	1	1
Other	35	8	20	65	423	58
All Groups	1287	747	652	1303	2843	1307
Total Biomass (mg/m^3)	340	246	181	284	263	171

Pronounced seasonal variations in total zooplankton abundance were apparent at all locations sampled in Lancaster Sound; however, seasonal patterns at most locations were different from one another. Cape Sherard and east mid-Lancaster Sound were most similar to each other in that zooplankton densities increased substantially from late August to mid-September. On a general level, total zooplankton numbers increased from about 1000 animals/m^3 in late July to 1600/m^3 in mid-September.

The depth distribution of zooplankton in Lancaster Sound was also quite variable among stations and times. In general, the depth distributions of zooplankton in Navy Board Inlet and west mid-Lancaster Sound were similar, but both differed from other locations; at the above-named stations substantially larger numbers of animals occurred at depths of 10 and 50 metres than at 150 metres, whereas at other stations average numbers at 10 and 50 m were little if any higher than at 150 m.

Average biomass of zooplankton was greatest at Cape Warrender (340 mg/m^3) and least at west mid-Lancaster Sound (171 mg/m^3) and east mid-Lancaster Sound (181 mg/m^3). Biomass at the remainder of the areas sampled averaged about 250 mg/m^3. Maximum average biomass occurred at a depth of 50 metres except at Cape Sherard and middle mid-Lancaster Sound, where higher averages occurred at 10 metres.

The contribution of major groups to total biomass of zooplankton is shown in Table 4-7. The overall importance of copepods is apparent. Other studies have also shown that copepods are the most important single group in terms of biomass throughout the Arctic (Zenkevitch, 1963; Grainger, 1965; Hopkins, 1969). Lancaster Sound is no exception.

4.2.3.2. Copepods

Copepods were the most diverse group of zooplankton in the upper 150 metres of Lancaster Sound with 20 species being recovered. However, only six species contributed significantly to total numbers and *Calanus hyperboreus* was most important in terms of biomass due to its large size. The most common species encountered are listed in Table 4-8. Disregarding taxonomic uncertainties concerning *Microcalanus*, all of the species are typical of Arctic waters (Grainger, 1965).

Table 4-7:
Total Biomass (per cent) Contributed by Major Zooplankton Groups in the Upper 150 m of Lancaster Sound Waters, July 22 to September 13, 1976 (from Sekerak *et al.*, 1976b).

	Station						
Major Group	Cape Warrender	Cape Sherard	East mid-Lancaster Sound	Middle mid-Lancaster Sound	Navy Board Inlet	West mid-Lancaster Sound	Overall (%)
Copepods	71.8	83.3	72.0	72.0	83.2	89.8	78.7
Larvaceans	0.9	0.5	0.6	1.4	4.2	1.7	1.6
Pteropods	7.4	3.0	14.8	14.7	3.3	0.5	7.3
Medusae	3.2	2.4	3.5	5.7	1.7	1.0	2.9
Chaetognaths	5.6	2.5	4.4	1.5	3.9	6.4	4.0
Amphipods	10.8	8.1	4.3	2.9	2.5	0.5	4.8
Others	0.2	0.1	0.2	1.8	1.1	0.1	0.6
Total	99.9	99.9	99.8	100.0	99.9	100.0	99.9

Table 4-8:
Distribution and Abundance (nos./m^3) of the Nine Most Common Copepods in Lancaster Sound (from Sekerak *et al.*, 1976b).

Species	Location						Mean
	Cape Warrender	Cape Sherard	East mid-Lancaster Sound	Middle mid-Lancaster Sound	Navy Board Inlet	West mid-Lancaster Sound	
Pseudocalanus minutus	554	249	148	249	585	499	381
Calanus hyperboreus	292	60	34	104	301	96	148
Calanus glacialis	191	63	68	203	205	140	145
Oithona similis	28	38	17	45	43	9	30
Metridia longa	35	4	5	11	18	29	17
Oncaea borealis	7	19	33	5	12	-	13
Microcalanus sp.	1	6	<1	-	-	2	1
Pareuchaeta glacialis	3	2	-	1	-	1	1
Acartia longiremis	-	-	-	2	1	-	1

4.2.3..3 Pteropods

Pteropods are unusual gastropods in that they are not confined to a substrate but swim actively in the water column. Only two species occur in the Arctic, Limacina helicina and Clione limacina. The latter species is large (up to about 5 cm in length) and preys exclusively upon L. helicina. In Lancaster Sound during the summer of 1976, the average density of C. limacina was only $0.7/m^3$, in contrast to 50.0 L. helicina/m^3 (Sekerak et al., 1976b). However, due to the large size of the former species it contributed disproportionately to pteropod biomass.

4.2.3.4. Amphipods

Five species of amphipods were recovered from the water column of Lancaster Sound in 1976 (Sekerak et al., 1976b). Hyperia galba, Onisimus glacialis and Apherusa glacialis were uncommon or rare. The latter two species are known to be associated with ice (Stephenson, 1942; Shoemaker, 1955; Buchanan et al., 1977), and dense concentrations of A. glacialis and O. glacialis were observed and collected in late August in Lancaster Sound as the ship was moving through fields of pan ice (Sekerak et al., 1976b). Therefore, individuals in the water column only represent a fraction of the total population present.

As its name implies, Parathemisto abyssorum is a deep water amphipod. It was collected at only two of 10 locations in the Canadian Archipelago surveyed by Mohammed and Grainger (1974), probably because deep waters were not sampled. In Lancaster Sound P. abyssorum was not abundant (average of $0.5/m^3$); larger numbers were collected in July than later in the summer, and densities where highest at Cape Warrender and Navy Board Inlet.

Parathemisto libellula was recovered in about the same average numbers as P. abyssorum. It was most abundant at Cape Warrender and largest numbers were collected at 50 metre depths. Parathemisto libellua is a predator of copepods and grows to a large size - up to 60 mm in length (Bowman, 1960). Its importance in food chains leading to vertebrates is discussed in Section 4.2.9.

4.2.3.5. Additional Groups and Species

Several other species of zooplankters were found in Lancaster Sound during 1976. Two species of larvaeceans, Fritilliaria borealis and Oikopleura vanhoeffeni, often occurred in large numbers ($500/m^3$) was not an uncommon est-

imate) but due to their small size they were relatively unimportant in biomass estimates.

Three species of chaetognaths (arrow worms) occur in Lancaster Sound. Densities during 1976 were low, normally 1 to $2/m^3$. In order of abundance, species present were Sagitta elegans, Eukrohnia hamata and Sagitta maxima. The first of these species was most abundant at 10 and 50 metre depths. Eukrohnia hamata was most common at 150 metres. Only three specimens of S. maxima were collected, all at 150 metres in east mid-Lancaster Sound. The importance of S. maxima in the first 150 metres of Lancaster Sound is minimal, but larger numbers probably occur in deeper waters.

Ctenophores (comb jellies) and coelenterates (jellyfish) were not abundant in Lancaster Sound, but due to their large size they sometimes were significant in the biomass of individual samples. Their importance in arctic food chains is obscure. Many of these specimens are extremely fragile and are destroyed in net collections. Recent data from SCUBA diver observations (Buchanan et al., 1977; LGL Ltd., unpubl. data) strongly suggest that the abundance of these animals has been seriously underestimated.

Most species of arctic benthic invertebrates do not have planktonic larvae (Thorson, 1936); hence the diversity of these larvae in the water column is not high, but they can be quite numerous. Larvae of polychaetes, bivalves, cirripedes and echinoderms were present in Lancaster Sound, with echinoderms being most numerous (up to $83/m^3$).

4.2.3.6. Regional Comparisons

As with phytoplankton, comparisons of the standing crops of zooplankton in Lancaster Sound and other regions must be performed with caution. Comparisons are difficult due to differences in sampling devices, depths sampled, season of study and expression of results. Data from the most comparable studies available are shown in Table 4-9. Densities of zooplankton in Lancaster Sound fall within ranges reported for other High Arctic areas, but averages for Lancaster Sound are substantially higher (the high estimates of abundance in Assistance Bay were due to unusually high numbers of copepod nauplii; a comparatively low biomass estimate resulted). Biomass estimates for Lancaster Sound during 1976 were considerably higher than those reported for most other arctic regions. It has been shown that biomass was generally greater at a depth of 50 metres in Lancaster Sound than at depths of 0, 10 or 150 metres. However, the density of animals between these depths is unknown and is of

Table 4-9:

Zooplankton Standing Crop in Lancaster Sound and Other Arctic Regions (modified from Sekerak *et al.*, 1976b*). All data are based on vertical tows with 230 to 240 μm mesh-size nets.

Area	Sampling Period	Depth Sampled (m)	Total Cell Count x 10^5 Average	Total Cell Count x 10^5 Maximum	Chlorophyll *a* (mg/m^3) Average	Chlorophyll *a* (mg/m^3) Maximum	Dominant Species	Reference
Lancaster Sound	July to September	0	22.8	38.7	1.23	5.16	*Chaetoceros socialis*	Sekerak *et al.*, 1976b
		10	26.9	51.3	1.77	6.45		
		25	24.8	37.9	2.47	13.62		
		50	5.9	10.8	0.93	3.87		
Igloolik (northern Foxe Basin)	July to September	0	~ 1.6*	~ 5.0	-	-	*Chaetoceros socialis*	Bursa, 1961a
		10	~12.3	~45.0	-	-		
		25	~ 2.9	~ 6.0	-	-		
		50	~ 1.9	~ 6.5	-	-		
Frobisher Bay, SE Baffin Island	August to September	0	13.7	39.9	-	-	*Chaetoceros socialis*	Bursa, 1971
		10	30.3	116.7	-	-		
		30	14.5	44.8	-	-		
Creswell Bay, Somerset Island	August	0	1.9	2.5	0.42	0.48	*Nitzschia seriata*	Sekerak *et al.*, 1976a
		10	7.4	9.6	0.58	0.62		
		50	6.3 (single sample)		1.41 (single sample)			
Assistance Bay, Cornwallis Island	August	0	10.3	25.2	1.07	1.75	*Chaetoceros socialis*	Sekerak *et al.*, 1976a
		10	12.7	18.2	2.06	3.05		
		20	6.6 (single sample)		2.25 (single sample)			
		40	13.8 (single sample)		1.36 (single sample)			
Bridport Inlet, Melville Island	August	0	0.6	1.1	0.17	0.34	*Chaetoceros socialis*	Buchanan *et al.*, 1977
		7.5	0.7	1.4	0.25	0.56		
		15	3.7	7.3	0.17	0.48		
		25	4.1	7.7	0.39	0.58		
Viscount Melville Sound (near Bridport Inlet)	August	0	3.0	5.4	.09	0.11	*Chaetoceros socialis*	Buchanan *et al.*, 1977
		7.5	1.5	2.1	.055	0.08		
		15	2.3	3.9	.075	0.08		
		25	46.9 (single sample)		1.04 (single sample)			

* Approximated from Figure 3 from Bursa (1961a)

importance in present comparisons. For example, if average densities are greater between 50 and 150 metres than between 0 and 50 m, the present estimates for Lancaster Sound would be larger than estimated for other areas where depths beyond 50 metres have not been sampled--even in the absence of regional difference. If, on the other hand, densities average lower between 50 and 150 metres than between 0 and 50 metres, estimates for Lancaster Sound would be low in comparison to other areas.

An additional consideration is that flow meters were used to calculate the actual volume of water filtered in zooplankton sampling in Lancaster Sound. Sampling of zooplankton in the other studies listed in Table 4-9 was performed without flow meters and the volume of water filtered was calculated from the mouth area of the net and the vertical distance sampled. Such calculations yield a theoretical maximum since they ignore resistance to filtration and clogging of the net. The overall result is that density estimates obtained without flow meters are always underestimates of true abundance. On this basis a correction factor of 1.34 could be applied to the Lancaster Sound averages; this correction factor accounts for only part of the apparently greater abundance and biomass in Lancaster Sound.

On the basis of present information it does appear that Lancaster Sound supports a denser zooplankton community than other arctic areas. This community is composed of herbivores and carnivores. The former group far out-weighs the latter in both biomass and numbers and is maintained by phytoplankton. Ultimately the large numbers of zooplankton in Lancaster Sound may be attributed to the same unknown physical factors that permit the development of a large phytoplankton community. Measurements from other areas, such as Jones Sound or eastern Hudson Strait where physical conditions may be similar, would be useful in placing Lancaster Sound in regional perspective. Results from zooplankton sampling in and near NW Baffin Bay during 1978 will, when available, be a useful basis for comparisons of Lancaster Sound, Baffin Bay and other areas.

4.2.4. Benthos

Approximately 450 species of benthic animals have been recorded to date in the arctic archipelago. The taxonomy and general distribution of many groups is known for the Canadian Arctic or can be extrapolated from work performed in the Russian Arctic and Greenland. However, detailed information (e.g. life histories, distribution in specific

areas) is far from complete for most groups and entirely lacking for others.

Only general trophic relationships among benthic species are known and their importance to vertebrates is also obscure in many cases. It is known that some shallow water benthic and intertidal animals form an important food source for some marine mammals and sea-associated birds for parts of the year. Walruses, bearded seals, beluga whales, eider ducks, arctic char and arctic cod feed on shallow water benthos. Many benthic animals utilize detritus as their major food source and are thus important in the recycling of organic matter. Trophic relationships of benthic animals are discussed in more detail in Section 4.2.9.

Little quantitative benthic research has been performed in the eastern Canadian Arctic. Ellis (1957) studied benthos in Eclipse Sound and in Arctic Bay. His general conclusions may or may not apply to larger areas. Throughout most of the Arctic, details of the distribution and abundance of benthic animals, prevalent benthic communities, and specific areas of especially rich and diverse benthic fauna are not known. Results of studies for Petro-Canada of benthic animals in offshore and nearshore parts of Baffin Bay are not yet available.

The term benthos refers to animals that live in close association with the sea bottom. Three broad categories of benthic animals can be defined (from Thorson, 1957):

1. Infaunal animals live in or on the soft sea bottom. They include burrowers, sedentary animals, and mobile animals that live at the substrate/water interface. The group includes gastropods, urchins, starfish, brittle stars, polychaetes, bivalves and some amphipods.

2. Epifaunal animals live permanently attached to hard substrates and include bryozoans, brachiopods, mussels, anemones, barnacles and hydroids. These animals may be found on rocks, seaweed and other live animals. Most species within this group are filter feeders.

3. Epibenthic animals live in close proximity to the bottom and are active swimmers. Mysids, decapods and some amphipods are included in this group. They may be filter feeders, scavengers or detritivores.

4.2.4.1. Infaunal Benthos

Infaunal benthic communities are named after the most conspicuous species present. Other animals, termed indicator species, are also used to characterize a community. The nature of the substrate is one of the most important factors determining the composition of the infaunal community in a specific area (Thorson, 1957; Sanders, 1960; Nichols, 1970). For this reason it is expected that when depth, temperature and salinity are constant, similar assemblages of animals should occur on or in similar substrates. These assemblages are termed communities and they have been used to characterize the infaunal benthos of various areas.

The study of the benthos of Pond Inlet and Arctic Bay by Ellis (1960) is the only one (previous to 1978) performed in the vicinity of Lancaster Sound or northwest Baffin Bay. He found that the infaunal benthos was characterized by an _Astarte borealis_ zone of the _Macoma_ community; abundance and biomass of animals found was comparable to that of other arctic areas (Table 4-10).

Other studies conducted in the Arctic Islands elucidate some features of the High Arctic benthos that may be applicable to Lancaster Sound and Baffin Bay. In two semienclosed bays, Cunningham Inlet (Somerset Island) and Bridport Inlet (Melville Island), this infaunal benthos was dominated by _Astarte borealis_ except in the vicinity of rivers where _Portlandia arctica_ communities were found (Thomson _et al._, 1975; Buchanan _et al._, 1977). In Creswell Bay, Somerset Island, Sekerak _et al._ (1976a) found a _Macoma_ community and two of its variations in the exposed outer bay. _Macoma_ sp. were relatively uncommon in the inner bay, where _Astarte borealis_ was the dominant bivalve except in an estuary where a _Portlandia arctica_ community was found. The information from Creswell Bay indicates that hydro-graphic parameters as well as depth and sediment type may be important in determining the distribution of benthic communities in the High Arctic.

Thomson _et al._ (1975) investigated the deep water (119 to 270 metres) benthos of West Barrow strait and Peel Sound. They found a low abundance of animals (Table 4-10) with brittle stars and polychaetes, especially maldanids, being the dominant animals.

4.2.4.2. Epifaunal Benthos

Epifaunal benthos may be a very important component of the secondary productivity of an area (Jansson and

Table 4-10:

Abundance and Biomass of Benthic Animals of Northern Baffin Island and other Arctic Areas (modified from Buchanan *et al.*, 1977).

Area	Depth Sampled (m)	Abundance Animals/m^2	Biomass g/m^2 (wet wt.)	Number of Samples	Reference
Eclipse Sound and Arctic	0-3	381	31	11	Ellis, 1960
Bay, North Baffin	5-14	1082	201	8	
Island	5-47	1815	438	23	
	7-55	987	200	20	
Bridport Inlet					Buchanan *et al.*, 1977
(Melville Island)					
Air lift samples	3-15	2652 ± 1638	211 ± 223	59	
Ponar grab samples	3-50	1887 ± 1526	142 ± 184	19	
Western Beaufort Sea					Carey *et al.*, 1974
Inner Shelf	23-30	1350 ± 195	33.3 ± 6.2	27	
Outer Shelf	46-52	2120 ± 165	50.8 ± 4.1	20	
Greenland					Ellis, 1960
Godthaab Fjord	10	1729	133	39	
Fortune Bay	5-10	1528	296	13	
Egesminde Harbour	5-10	432	320	10	
Mudderbught	5-10	1507	48	12	
Greenland					Vibe, 1939
Upernavik (Gamnel,					
Skibshavn & Sigrids Havn)	10-19	187	387	13	
Prøvens Havn	8-19	490	1482	7	
Frustration Bay	5	282	35	6	Ellis, 1960
(Foxe Basin)	15	209	210	4	
Creswell Bay	3- 5	386	-	10	Sekerak *et al.*, 1976a
(Somerset Island)	3-15	578	-	24	
	16-30	1374	-	8	
	31-50	1663	-	6	
Cunningham Inlet	3- 5	884	-	5	Thomson *et al.*, 1975
(Somerset Island)	3-14	1400	-	16	
	20-40	1293	-	6	
Barrow Strait -	119-191	394	-	10	Thomson *et al.*, 1975
Peel Sound	220-270	346	-	5	

Kautsky, 1977). However, epifaunal animals, other than those living in the intertidal zone, have to date received scant attention due to great difficulties encountered in sampling these animals. Many workers have studied the colonization of test plates (reviewed in Buchanan, 1975) rather than natural communities. Increased use of SCUBA divers in marine investigations is now permitting quantitative studies of the abundance and distribution of animals on shallow water hard substrates.

There appear to be no published accounts of the ecology of the epifauna of hard substrates in the Canadian Arctic. Some observations by Sekerak et al. (1976a) on the cobble substrates of Assistance Bay, Cornwallis Island, and by W. Cross (LGL Ltd., unpubl. data) indicate that hard substrates in the High Arctic may be extensively colonized by plants and animals. In Assistance Bay the majority of rocks taken by grab sample were covered by encrusting coralline algae. Barnacles were found to a depth of 50 metres and serpulid polychaetes, gastropods, chitons, bryozoans, sea urchins and brachiopods were also recovered from cobble bottoms. In addition to the above, tunicates, anemones, hydroids, sponges, mussels, some tubicolous polychaetes and macrophytic algae have been observed attached to scattered cobble and boulders in various locations in the Canadian archipelago (LGL Ltd., unpubl. data).

4.2.4.3. Epibenthic Animals

Reliable quantitative data concerning epibenthic animals are unavailable for any Arctic area, primarily because the mobile nature of many epibenthic species makes sampling difficult. Qualitative information indicates that the most common epibenthic animals encountered in the Arctic are decapods, mysids and amphipods. Although the shallow 'barren' zone is almost totally devoid of infauna, it is often teeming with mysids and amphipods. In some areas mysids (*Mysis litoralis* and *M. oculata*) form dense shoals along the coast in shallow water and among grounded pan ice (LGL Ltd., unpubl. data). Amphipods, especially *Onisimus litoralis* and *Gammarus setosus*, are also common in the barren zone. Epibenthic invertebrates can be important as food for fish and marine birds in nearshore arctic areas (Craig and Griffiths, 1978; Johnson, 1978).

Below the barren zone decapods are common, especially among kelp fronds. Many species of amphipods are found below the barren zone (Sekerak et al., 1976a; Buchanan et al., 1977), but they are not as abundant as in shallower waters.

4.2.4.4. Intertidal Animals

Much of the High Arctic intertidal zone is composed of cobble beaches with some areas of sand, boulders or exposed bedrock and cliffs. For most of the year the intertidal zone is occupied by fast ice. During the open water season it is continually abraded by pan ice and subjected to great variations in temperature and salinity.

The above-mentioned factors preclude the establishment of faunal assemblages typical of temperate shores and have relegated this area primarily to hardy mobile amphipods, chiefly *Gammarus setosus* and *Onisimus litoralis* (Sekerak *et al*., 1976a; Buchanan *et al*., 1977; LGL Ltd., unpubl. data). *Onisimus litoralis* prefers sandy substrates, while *Gammarus setosus* is more abundant on cobble beaches (Steele, 1961; Steele and Steele, 1970). Buchanan *et al*. (1977) found amphipod densities up to 3584 individuals/m^2 in intertidal regions of Bridport Inlet, Melville Island. They also reported a mass stranding of zooplankton. In this region densities of copepods reached 10,452 individuals/m^2. Alliston *et al*. (1976) have shown that such strandings can be an important food source for sea-associated birds, especially shorebirds.

4.2.5 Marine and Anadromous Fish

In comparison to the waters of West Greenland, where 86 fish species are known to occur (Hildebrand, 1948), Lancaster Sound and northwest Baffin Bay are regions of low species diversity. For example, only 23 species are known or suspected to occur in Lancaster Sound or adjacent parts of Baffin Bay (Table 4-11). However, due to the lack of exploratory fisheries research, additional species may be present. Little detailed biological information concerning most of the species listed in Table 4-11 is available. Species accounts will, therefore, be restricted to the species for which relevant information is available.

4.2.5.1 Greenland Shark

The distribution of Greenland sharks in the Canadian Arctic is poorly known. They have been taken in Eclipse Sound (Mary-Rousseliere, 1959) and Koluktoo Bay, north Baffin Island (Beck and Mansfield, 1969). Though apparently a deep-water species--recorded as being caught a maximum of 700 metres deep in Greenland waters--Greenland sharks are caught by West Greenland Eskimos by jigging with 'light' hooks and lines under the ice during winter (Jensen, 1948). During the

Table 4-11:
Common and Scientific Names[1] of Fish Species Known or Suspected to Occur in Lancaster Sound and Immediately Adjacent Waters.

Name		
Scientific	Common	Reference
Squalidae		Beck and Mansfield (1969)
Somniosus microcephalus	Greenland Shark	Mary-Rousselière (1959)
Rajidae		
Raja hyperborea	darkbelly skate	Jensen (1948)
Salmonidae		
Salvelinus alpinus	arctic char	Ellis (1962)
Gadidae		
Arctogadus glacialis	polar cod	Nielsen and Jensen (1967)
Boreogadus saida	arctic cod	Bohn and McElroy (1976), Sekerak *et al.* (1976b)
Gadus ogac	Greenland cod	Walters (1955)
Macrouridae		
Coryphaenoides rupestris	rock grenadier	Ellis (1962)
Zoarcidae		Ellis (1962)
Gymnelis viridis	fish doctor	LGL Ltd., (unpubl. data)
Lycodes mucosus	saddled eelpout	suspected
Lycodes polaris	polar eelpout	LGL Ltd., (unpubl. data)
Cottidae		
Artediellus scaber	rough hookear	suspected
Gymnocanthus tricuspis	arctic eelpout sculpin	Ellis (1962) LGL Ltd., (Unpubl. data)
Icelus bicornis	twohorn sculpin	Ellis (1962)
Icelus spatula	spatulate sculpin	LGL Ltd., (unpubl. data)
Myoxocephalus quadricornis	fourhorn sculpin	Ellis (1962)
Myoxocephalus scorpioides	arctic sculpin	Ellis (1962) LGL Ltd., (unpubl. data)
Myoxocephalus scorpius	shorthorn sculpin	Ellis (1962) LGL Ltd., unpubl. data)
Triglops pingelli	ribbed sculpin	suspected
Cyclopteridae		
Cyclopteropsis jordani	smooth lumpfish	Ellis (1962)
Eumicrotremus derjugini	leatherfin lumpsucker	LGL Ltd., (unpubl. data)
Eumicrotremus spinosus	Atlantic spiny lumpsucker	LGL Ltd., (unpubl. data)

Table 4-11 continued:

Name		
Scientific	Common	Reference
Liparis tunicatus	Greenland seasnail	LGL Ltd., (unpubl. data)
Pleuronectidae		
Reinhardtius hippoglossoides	Greenland halibut	(K.J. Finley, pers. comm.)

[1] Scientific and common names are from Legendre *et al.* (1975).

open-water season, the Greenland shark is often attracted to surface waters by offal from sealing or whaling operations (Beck and Mansfield, 1969).

Growth rate and age at maturity of the Greenland shark are unknown. However, Beck and Mansfield (1969) reported that males up to 311 cm long and females up to 295 cm caught at Koluktoo Bay, Baffin Island (72°06'N; 80°47'W), were sexually immature. The largest Greenland shark known is reported as being 731 cm long (Dunbar, 1970).

The food of the Greenland shark consists of carrion (Hildebrand, 1948), fish and seals (Dunbar and Hildebrand, 1952), egg cases of Raja hyperborea (Beck and Mansfield, 1969) and large invertebrates (Jensen, 1948). This species, although not exploited either on a subsistence or commercial basis in the eastern Canadian Arctic, is part of the Danish commercial catch in Greenland waters. In Greenland, the annual production of shark liver, which has a high vitamin A content, was approximately 700 tons in the period 1931-1939; in 1952, it was 358 tons (Dunbar, 1970).

4.2.5.2 Arctic Char

Salvelinus alpinus has a circumpolar distribution and is the most northerly distributed of the freshwater fishes. Arctic char may either be anadromous, migrating to sea in the spring and returning to fresh water in the fall, or remain permanently in fresh water. Resident char are often isolated from the sea by waterfalls or other barriers.

Because of their great subsistence, sport and commercial value, considerable research has been devoted to the biology and systematics of arctic char throughout their range. For detailed information, the reader is referred to the extensive arctic char bibliography by Marshall (1977). While at sea, arctic char feed along shallow, nearshore coastal areas (Sekerak et al., 1976a) and may travel as much as 35 or 40 km away from their natal stream. The marine diet of arctic char includes a variety of crustaceans and is discussed in Section 4.2.9.

The distribution of anadromous arctic char along the shores of Lancaster Sound, Eclipse Sound and western Baffin Bay is known to varying degrees. It is doubtful if any occur in eastern Lancaster Sound due to lack of suitable fresh water habitats (LGL Ltd., unpubl. data). Anadromous char occur in about six or seven drainages in the Eclipse Sound - Pond Inlet area. Major char streams include the Robertson River draining into Koluktoo Bay and the Salmon

River near the settlement of Pond Inlet. The distribution of anadromous char along northeastern Baffin Island is poorly documented. In general, suitable fresh water habitat is more common than in more northerly regions; therefore, anadromous char are likely to be found in the summer in many of the fjords.

Anadromous arctic char are extensively utilized by Inuit as food for themselves and their dogs. This is especially true in the eastern High Arctic where anadromous arctic char are the only large and relatively accessible fish available. Commercial fisheries operating in the central Arctic and Labrador market from about 45,000 to 91,000 kg of arctic char annually (Scott and Crossman, 1973).

4.2.5.3. Gadids (Cods)

Of the three cod species listed in Table 4-11, arctic cod (*Boreogadus saida*) and Greenland cod, (*Gadus ogac*) are known to occur in the study area (Sekerak *et al.*, 1976b); LGL Ltd., unpubl. data). The polar cod (*Arctogadus glacialis*) has been taken in the adjacent water of Smith Sound and northeastern Baffin Bay (Nielsen and Jensen, 1967). Of the cods that may be present, the arctic cod appears to be by far the most important.

The arctic cod is extremely important in food chains of arctic seas, since it acts as a major link in the energy flow from primary and secondary producers to the top-level carnivores. The reader is referred to Section 4.2.9 for a detailed account of the role of arctic cod in arctic food webs. Because of its importance in arctic food webs a summary of current knowledge about arctic cod is given below.

Arctic cod have a circumpolar distribution and prefer colder arctic waters. The arctic cod is described as a 'cryopelagic' species (Andriashev, 1970), and is often found in association with sea ice (Jensen, 1948; Dunbar and Hildebrand, 1952; Andriashev, 1954; Walters, 1955; Ponomarenko, 1968; McAllister, 1975), especially in the region of the southern limit of pack-ice (Andriashev, 1954). However, during the ice-free season (late summer and early fall), this species often concentrates in coastal regions (Hognestad, 1968; Ponomarenko, 1968; Rass, 1968; Bain and Sekerak, 1978). Arctic cod undertake seasonal feeding and spawning migrations in the Barents, Kara, Laptev, East-Siberian and Chukchi Seas (Ponomarenko, 1968). In the Canadian Arctic, concentrations of arctic cod have been observed in late summer or fall in Allen Bay, Cornwallis Island, during 1976 and 1977 (Bain and

Sekerak, 1978) and along the west shore of Navy Board Inlet (LGL Ltd., unpubl. data).

Arctic cod spawn in winter, but whether the spawning sites are in coastal waters or offshore (along the ice edge of Soviet waters) is still debated (Andriashev, 1954; Hognestad, 1968; Rass, 1968). No arctic cod spawning sites have as yet been located in the North American Arctic. Arctic cod eggs are pelagic, floating under the surface of the water, and, as such, are susceptible to prevailing currents. Larval cod hatch in April and May, and sometimes as late as July (Nikolskii, 1961; Rass, 1968). Newly hatched larvae are about 5 mm long (Rass, 1968) and by the end of their first growing season arctic cod are 30 to 70 mm long (Andriashev, 1954; Hognestad, 1968). Their life span is 6 to 7 years (Andriashev, 1954) and typical maximum adult length is approximately 240 mm.

In Lancaster Sound, Sekerak et al., (1976b) reported the average density of young-of-the-year arctic cod as 5.2/100 m^3 in the upper 150 metres of water. This was substantially higher than the density (2.8/100 m^3) found by Quast (1974) in the upper 50 metres of water in the Chuckchi Sea. Despite their relatively small size, arctic cod are potentially of commercial value. During the winter, the large liver (up to 10% of body weight) contains about 50% valuable oil (Nikolskii, 1961). However, nowhere in the Canadian Arctic is the arctic cod used as a food source for humans.

4.2.5.4 Other Fishes

Most of the other fish species known or suspected to occur in the study area are small demersal forms such as sculpins, eelpouts, lumpfish and seasnails (Table 4-11). In general, the ecological significance of these fishes is unknown.

One additional fish of potential importance is the Greenland halibut. A flat fish species, presumably the Greenland halibut, has been reported as part of the longline catches by residents of Pond Inlet, and Greenland halibut are part of the diet of narwhal (LGL Ltd., unpubl. data). Based on its known distribution and temperature range (generally, between -1 and +4°C; Lear, 1970), Greenland halibut probably occur in eastern Lancaster Sound and northwestern Baffin Bay. Immature and adult Greenland halibut are bottom-dwellers found in deep water (250-1600 metres deep) along the west coast of Greenland as far north as Smith Sound (Jensen,

1935). In Canadian waters they are common, at least north to southern Baffin Island (Leim and Scott, 1966).

Adult Greenland halibut attain a length of about 100 cm and a weight of 5 to 10 kg. Lear (1970) reported Greenland halibut as old as 21 years in Newfoundland waters. This species is of considerable commercial value to the Greenland and Danish fisheries and is also an important part of the Newfoundland fisheries.

4.2.6 Sea-Associated Birds

The following review of the populations of sea-associated birds using the NW Baffin Bay-Lancaster Sound area is based primarily on studies conducted by Norlands Petroleums. These studies consisted of a series of aerial survey transects over eastern Lancaster Sound carried out at weekly intervals from 2 May to the end of September, 1976 (Johnson *et al.*, 1976a) and shipboard observations from mid-July to early September 1976 (Bradstreet, 1976). Detailed studies of the food habits of pelagic seabirds were also conducted (Bradstreet, 1976). Relevant literature is cited where appropriate. A limited amount of information from surveys conducted over NW Baffin Bay in 1978 by Petro-Canada is included, but most results of these surveys are not yet available.

The distribution, abundance and habitat of the more common species are discussed in general in the following species accounts. Uncommon species are only briefly reviewed. Information on the food habits of the common species is presented in section 4.2.9.1 (trophic relationships section).

4.2.6.1 Northern Fulmar

The Northern Fulmar (*Fulmarus glacialis*) is a pelagic seabird that nests in colonies on coastal cliffs in arctic and sub-arctic areas of both the New and Old Worlds. Fulmars are abundant in the Lancaster Sound-Baffin Bay area. Locations of known colonies are plotted on Figure 4-45. The nine colonies have been estimated to contain about 180,000 breeding pairs of fulmars (Brown *et al.*, 1975; Nettleship and Gaston, 1978; LGL Ltd., unpubl. data); birds from all of the colonies probably use NW Baffin Bay at some time each year. The subspecies of fulmar that nests in Lancaster Sound winters in offshore waters of southern Baffin Bay, Davis Strait and in the North Atlantic (Salomonsen, 1950; Fisher, 1952).

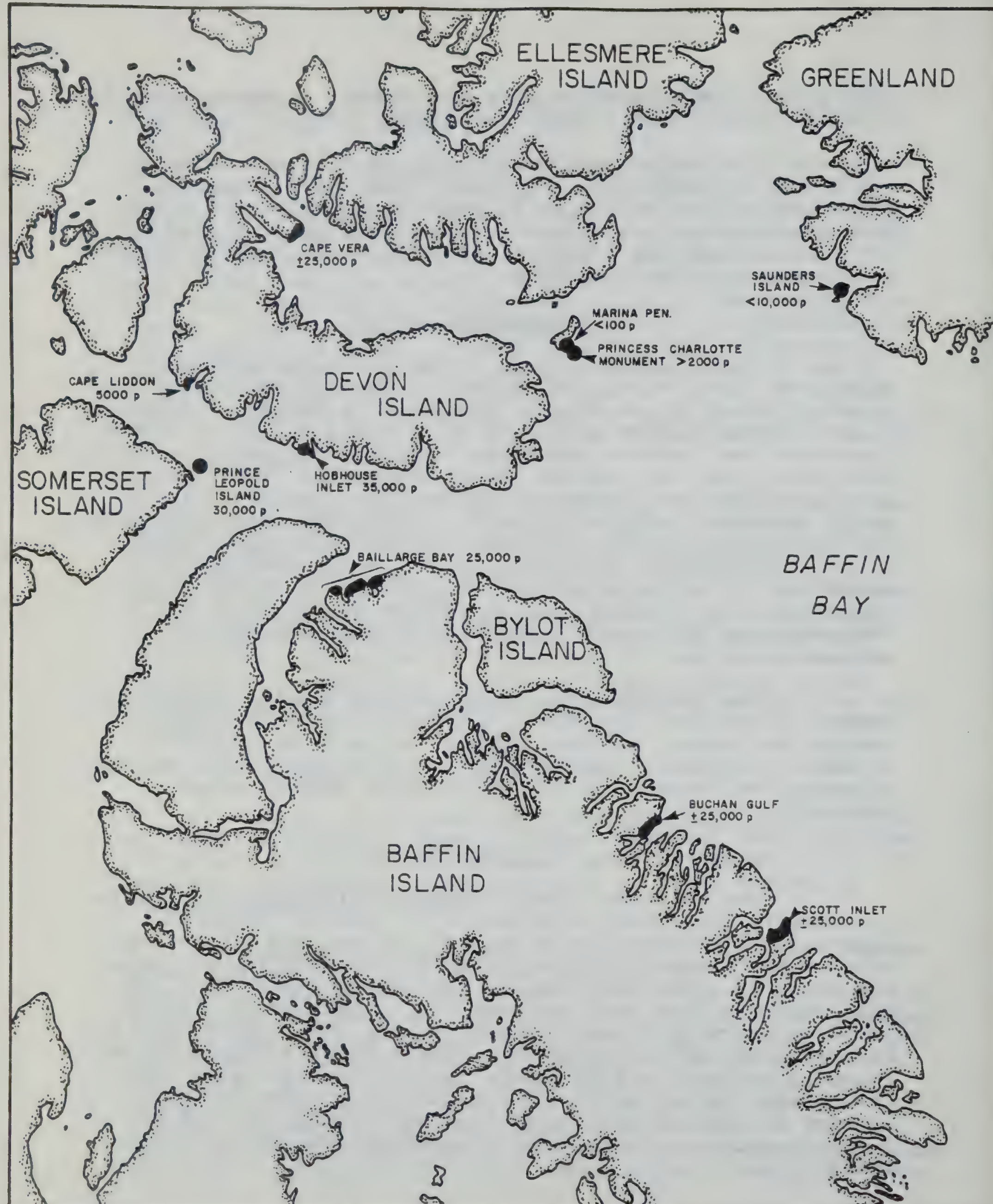


Figure 4-45

Locations of Northern Fulmar Colonies in the Lancaster Sound--NW Baffin Bay Area. Data are from Brown *et al.* (1975) and LGL Ltd. (unpublished). On this and other figures of this type, p = pairs.

Fulmars have been observed in Lancaster Sound in spring as early as 23 April (Hørring, 1937); in 1978 no fulmars were seen during aerial surveys of the North Water polynia in March and April (LGL Ltd., unpubl. data). A few were present at the Prince Leopold Island colony on 2 May 1976 and over half the breeders were present by 10-12 May (D. Nettleship, Can. Wildl. Serv., pers. comm.). Most fulmars were absent from the Prince Leopold Island colony in the last half of May 1976 during the 'pre-egg exodus'; large numbers began to return after 2 June and the first egg was laid on 4 June 1976 (D. Nettleship, pers. comm.).

Because the data from northwest Baffin Bay in 1978 are not yet analyzed, the following review presents the status of fulmars in eastern Lancaster Sound in 1976. It is based on Norlands Ltd. (1978). In 1976, fulmars were present in the eastern Lancaster Sound study area when surveys began on 2 May and they were present until the study ended on 28 September. During May, fulmars were widespread in low densities throughout offshore waters; estimated numbers in offshore waters (over 7 km from shore) ranged from 1000 to 9000 birds during the five surveys. A minor influx of fulmars (estimated at 17,000) occurred on 6-7 June and most of these birds were concentrated along the north coasts of Bylot and Baffin Islands (Johnson et al., 1976a). Since nesting fulmars reoccupy their high Arctic nesting colonies in April and May, most of the 190,000 birds that nest west of eastern Lancaster Sound must have passed through eastern Lancaster Sound in late April or May. This movement was not detected during the five weekly surveys conducted by Johnson et al., (1976a).

The first major influx of fulmars detected during the surveys occurred in late June 1976 when an estimated 64,000 birds were present. High concentrations occurred along the southern margin of the sound and large numbers (about 40,000) were estimated in offshore waters over 7 km from landfast ice-edges and ice-free coasts; a majority of these birds were in the south half of the study area (Figure 4-46).

The numbers of fulmars in eastern Lancaster Sound remained high through July and August. During July, dense concentrations of fulmars were found only at the ice-edges remaining in the study area - across Croker Bay and Navy Board Inlet. (Figure 4-47). However, large numbers remained in offshore waters until 25-26 July when over 50,000 fulmars were estimated in waters over 7 km from shore or ice-edges. Densities of the offshore birds were higher in the southwest

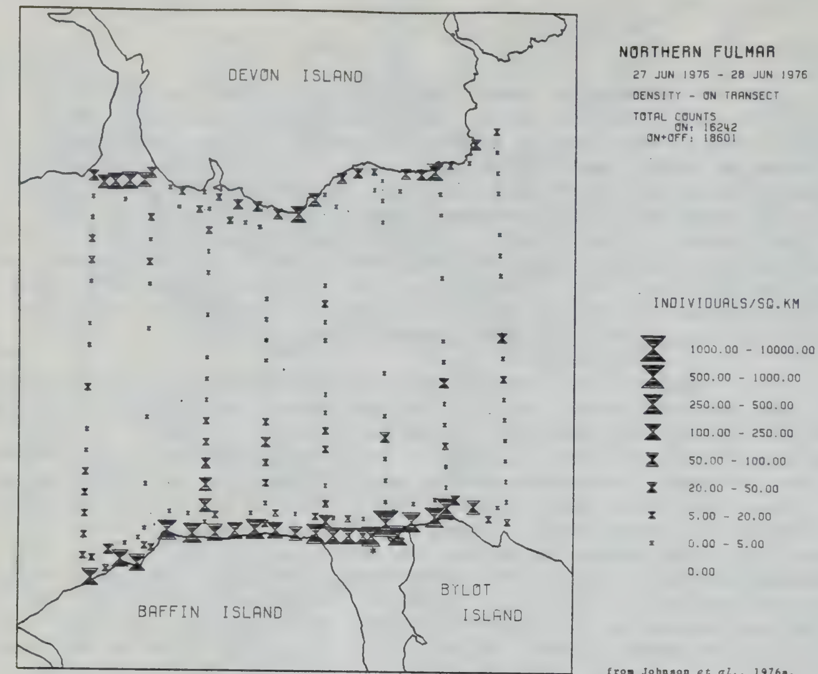


Figure 4-46: Northern Fulmar counts.

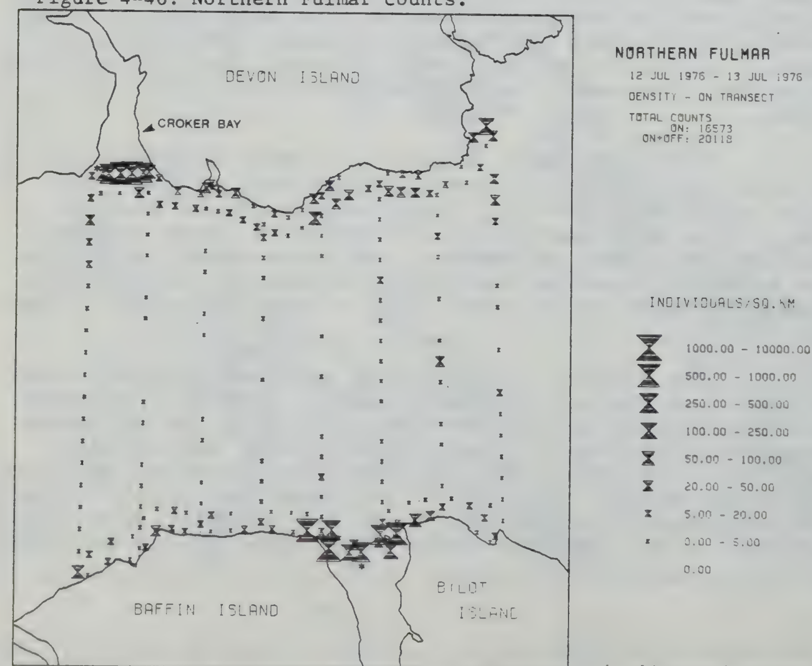


Figure 4-47: Northern Fulmar counts.

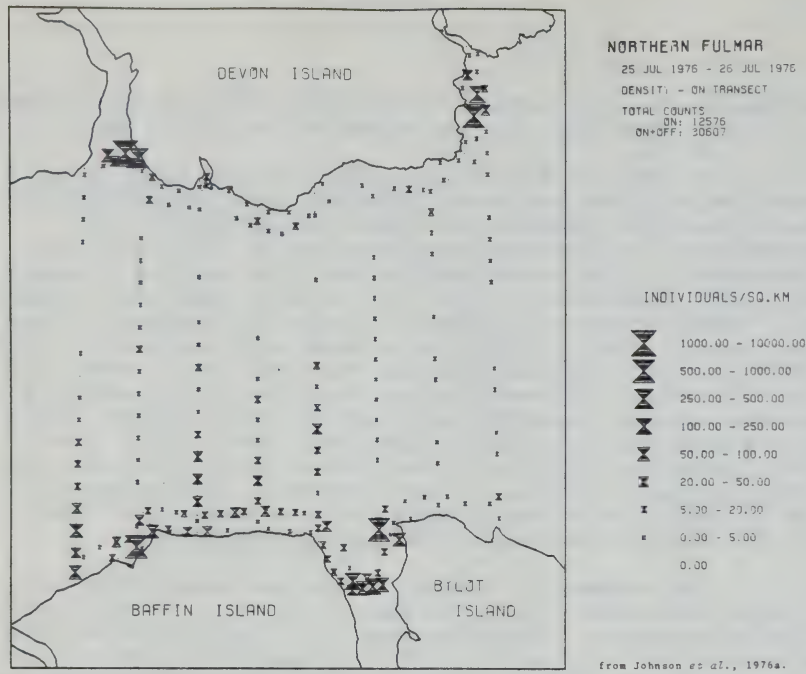
quadrant of the study area (Figure 4-48). This is the closest part of the study area to the colony at Baillarge Bay.

Between 26 and 31 July 1976 a major build-up of fulmars began along the south coast of Devon Island and in adjacent nearshore waters (Figures 4-48 and 4-49). The concentration in this area persisted until 12-13 September (Figure 4-50). This concentration was also present in early August 1972 (Nettleship, 1974) and in 1978 (LGL Ltd., unpubl. data). Total numbers of fulmars in eastern Lancaster Sound during August (about 75,000) were apparently similar to those in July, but the distribution was very different--over half of the individuals present during August were in coastal and nearshore waters, primarily adjacent to Devon Island, while the rest were farther than 1.4 km from shore. Only about 15,000 individuals (20% of those in the study area) were in offshore waters more than 7 km from shore (Johnson et al., 1976a). During this period many fewer fulmars were found along the southern margin of eastern Lancaster Sound.

The number of fulmars in eastern Lancaster Sound increased from about 75,000 in August to about 88,000 birds on 12-13 September. This increase coincided with a decline from about 70,000 fulmars to 40,000 fulmars, in western Lancaster Sound and eastern Barrow Strait, between 29 August and 11 September 1976 (Nettleship and Gaston, 1978).

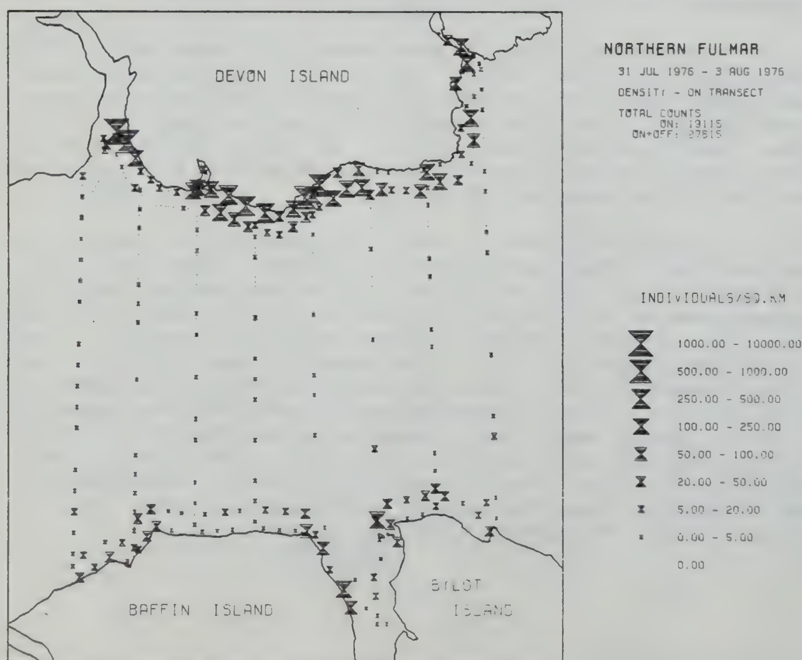
Between 13 and 19 September 1976 over 80% of the fulmars left the study area. Relatively few fulmars were found along the coast of Devon Island but there were some concentrations along the coasts of Bylot and Baffin Islands in the last 10 days of September. In 1978, the numbers of fulmars began to decline in mid-September and none were seen after the first week of October.

Northern Fulmars are long-lived birds (mean life expectancy of boreal race males 33.9 years, females 35.5 years-Dunnet and Ollason, 1978) with a low annual rate of reproduction. Only one egg is laid per pair, and only half of the eggs produced fledged young at Prince Leopold Island in 1975 (Nettleship, 1977). The average age of first breeding by fulmars is 9.2 years at a boreal colony (Ollason and Dunnet, 1978). This delayed maturity and the low annual production of young imply that impacts affecting only a single year's production of young will probably have a relatively small effect on the overall population size. However, impacts affecting breeding adults could have severe, long-lasting effects on population size.



from Johnson *et al.*, 1976a.

Figure 4-48: Northern Fulmar counts.



from Johnson *et al.*, 1976a.

Figure 4-49: Northern Fulmar counts.

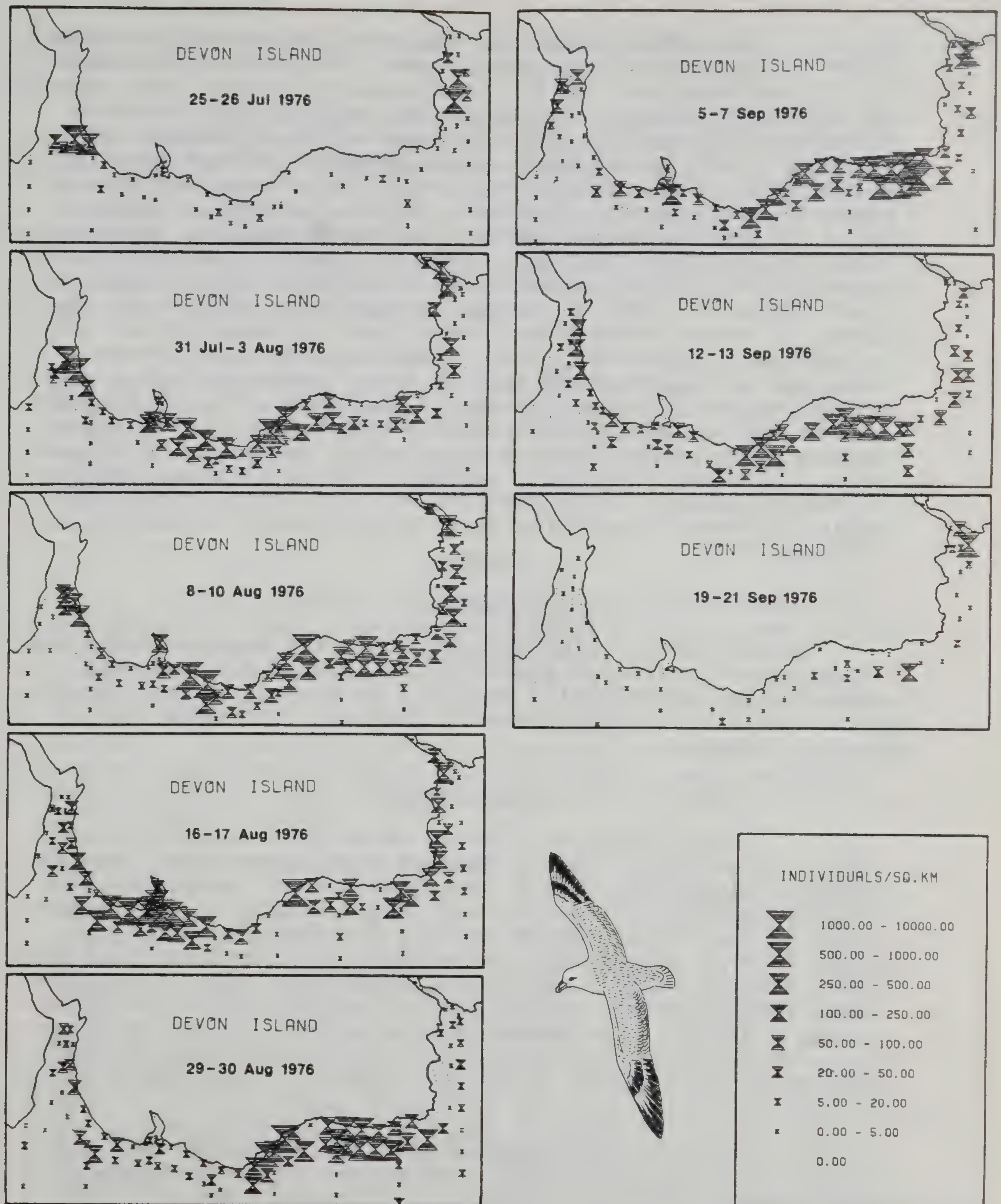


Figure 4-50.

Distribution of Northern Fulmars Along the SE Coast of Devon Island During Each Weekly Survey, 25 July - 21 September 1976. The survey on 22 August has been excluded. Data are from Johnson *et al.* (1976a).

The distribution of non-breeding sub-adult fulmars (ages 1 to 7 years) is poorly known. Nettleship and Gaston (1978) estimate that 40,000 non-breeding fulmars were present at the Prince Leopold Island colony (with 60,000 breeding birds) in 1976 but the age of these birds is unknown. They occupied cliff ledges, perhaps in preparation for nesting in a following year. Salomonsen (1967) found that one and two year old fulmars did not return to the vicinity of their natal colony in Umanak District of West Greenland; some three year olds and many four year olds returned to the area but it is not known if they occupied the nesting colony. Macdonald (1977) showed a similar pattern in the distribution of pre-breeding boreal fulmars and found that the mean age of return to land is five years. Since fulmars do not, on average, breed until 9.2 years of age, it seems probable that significant numbers of 4 to 7 year old sub-adult fulmars would be present in Lancaster Sound in the summer. It is not known whether these sub-adults contributed to the increase in numbers of fulmars in eastern Lancaster Sound in late June and to the subsequent concentrations of birds along the south coast of Devon Island from late July to early September in 1976 and 1978.

4.2.6.2 Brant

The Brant (Branta bernicla) is a holarctic species of marine goose; it is a widely distributed but uncommon nesting bird in the high Arctic. In the study area, Brant occur locally in small numbers; they are restricted to coastal waters.

4.2.6.3 Snow Goose

The population of Snow Geese that nests in the eastern high Arctic is the Greater Snow Goose (Chen caerulescens atlantica). Major concentrations of nesting birds occur on northern Baffin Island, Bylot Island and Ellesmere Island with smaller groups nesting on Somerset, Devon, Bathurst and Axel Heiberg Islands and in Greenland (Bellrose, 1976; Palmer, 1976a). The total population of Greater Snow Geese was estimated at 66,770 ± 5% in May 1968 and 84,000 in spring of 1970 by J.D. Heyland (in Palmer, 1976a). In October, the population was estimated at 120,000 birds in 1970 (Heyland, in Bellrose, 1976) and 150,000 in 1971 (Heyland, in Palmer, 1976a).

Greater Snow Geese winter along the mid-Atlantic coast of the United States. Migrations to and from the breeding grounds are conducted at high altitudes with few

stopovers en route. Greater Snow Geese arrive in the study area in June and most have left by early September.

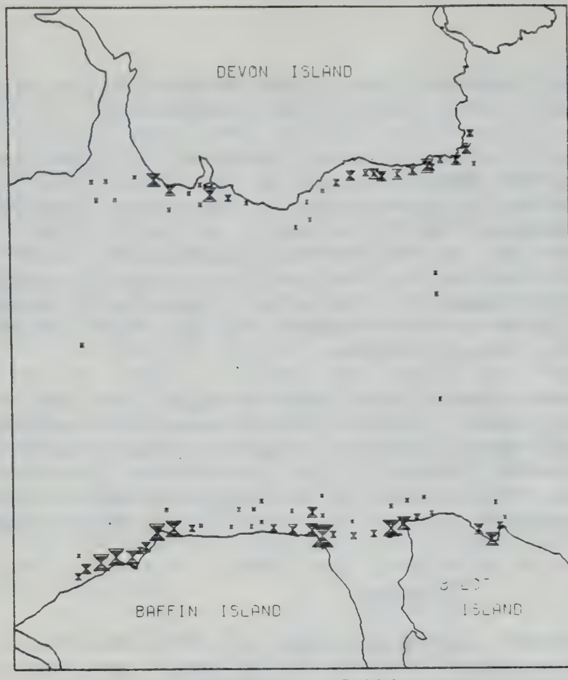
The largest known group of breeding Greater Snow Geese occurs along the coastal plain of southwest Bylot Island where 20,000 birds nest in small scattered colonies of 25 to 300 nests (Lemieux, 1959; H. Boyd, in C.W.S., 1972). Greater Snow Geese also nest on coastal tundra and river valleys in Admiralty Inlet, on the lowlands south of Eclipse Sound and Pond Inlet, coastal tundra along southeast Devon Island, and on Philpots Island (Johnson et al., 1976a; Kemper, 1976; LGL Ltd., unpubl. data).

Most Greater Snow Geese nest within a few km of seacoasts (Lemieux, 1959). During brood-rearing, moulting and staging for fall migration, Greater Snow Geese occasionally use marine waters, primarily for protection from terrestrial predators. The geese are grazers of tundra vegetation and they probably do not rely heavily on marine waters for food.

4.2.6.4 Oldsquaw

The Oldsquaw (Clangula hyemalis) is a holarctic breeding duck that winters in both the Atlantic and Pacific Oceans (Palmer, 1976b). It nests in suitable habitat throughout the Canadian Arctic (Godfrey, 1966; Bellrose, 1976). The Oldsquaw is a common species in eastern Lancaster Sound and NW Baffin Bay where it is present from May through October. The winter range of these individuals is not known but may include coastal waters of SW Greenland, Labrador, Atlantic Canada and the northeastern United States (Bellrose, 1976; Palmer, 1976b).

Oldsquaws are present in the study area from May to early October. The main influx of spring migrants occurs in June and early July. Most of these birds are apparently transients that use the waters of the study area for feeding prior to moving north and west to nesting areas. It is not known how long these transients stop in the study area and, thus, the total number of individuals that use the area in June and early July cannot be determined. Spring migrants stage in shallow, coastal waters but the locations vary with ice conditions. In 1976, flocks of 2500 and 1500 Oldsquaws were found near Adams Island at the west side of the entrance to Navy Board Inlet on 27 June. Smaller concentrations occurred along the coast of Devon Island, near and west of Cape Sherard and in the Dundas Harbour-Croker Bay area (Figure 4-51). In 1978, these areas were ice-covered until late July and Oldsquaws were concentrated along the east



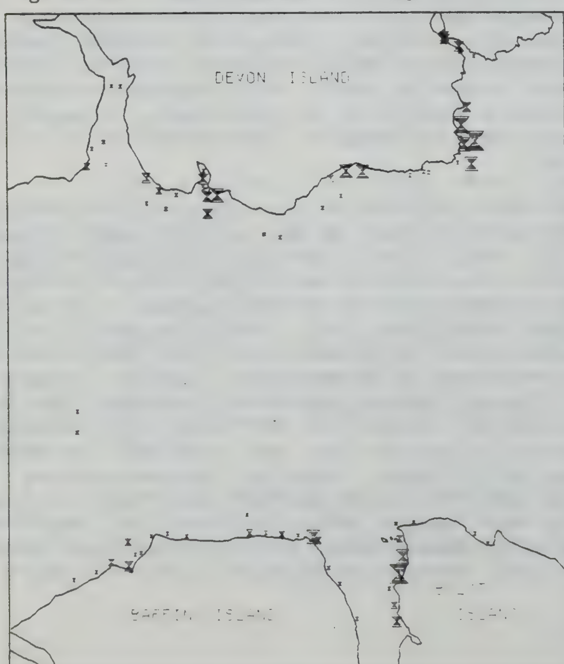
Distribution of Oldsquaws, 13 Jun - 13 Jul 1976. Values plotted are mean numbers on + off transect. Most observations along nearshore transects were off-transect on the landward side.
Total count:
On-transect: 8162
On + off transect: 13087

INDIVIDUALS

1000 - 5000
500 - 1000
250 - 500
100 - 250
50 - 100
20 - 50
5 - 20
0 - 5

from Johnson *et al.*, 1976a.

Figure 4-51: Distribution of Oldsquaws.



Distribution of Oldsquaws, 16 Aug 1976 - 28 Sep 1976. Values plotted are mean numbers on + off transect. Most observations along nearshore transects were off-transect on the landward side.
Total count:
On-transect: 6311
On + off transect: 10931

INDIVIDUALS

1000 - 5000
500 - 1000
250 - 500
100 - 250
50 - 100
20 - 50
5 - 20
0 - 5

from Johnson *et al.*, 1976a.

Figure 4-52: Distribution of Oldsquaws.

coast of Devon Island, in the mouth of Jones Sound and along the coast of Coburg Island.

Several hundred to a few thousand moulting Old-squaws are present in the study area in August. These are found primarily along the coast of southeast Devon Island and along southwest Bylot Island. The number of Oldsquaws in the study area increases steadily throughout September as post-moulting birds (either post-breeding or non-breeding) arrive from areas west and north of the study area. The average coastal distribution for the six surveys conducted from mid-August to late September 1976 is plotted on Figure 4-52; these areas were used again in 1978. The coasts of Navy Board Inlet and Pond Inlet, and the Baffin Island coast south to Coutts Inlet, were also important in 1978. Virtually all Oldsquaws have left the study area by early October.

Oldsquaws probably do not nest until they are two years old and the clutch-size averages about 7 eggs (Alison, 1972; Bellrose, 1976; Palmer, 1976b). There are no quantitative data on the reproductive rate of Oldsquaws in the high Arctic. The arctic distribution of non-breeding yearlings has not been studied; thus, it is not known whether these birds are present in the northwest Baffin Bay-Lancaster Sound area.

4.2.6.5 Eiders

Two species of eiders frequent the eastern high Arctic: the King Eider (*Somateria spectabilis*) and the Common Eider (*Somateria mollissima*). Both species are holarctic in distribution and are widespread in the Canadian Arctic (Godfrey, 1966). The populations of Common Eiders (*S.m. borealis*) and King Eiders that inhabit the NW Baffin Bay-Lancaster Sound area probably winter in coastal waters off southwestern Greenland, southern Baffin Island, Labrador, the Maritime provinces of Canada and the northeastern United States (Salomonsen, 1950, 1968; Bellrose, 1976; Palmer, 1976b). Migration routes to and from the study area are unknown but are assumed to follow the waters of Baffin Bay although both species are known to undertake high level, overland migrations on some occasions (Wynne-Edwards, 1952; Gauthier *et al*., 1976).

The females of the two eider species are very similar in appearance and cannot be distinguished during aerial surveys. Thus, during the studies in 1976 and 1978, females were identified only when they accompanied the readily identifiable males. The King Eider was the most common duck in eastern Lancaster Sound in 1976, and in the larger study area

in 1978. The Common Eider was moderately common. Patterns of eider movement were quite similar in 1976 and 1978. Both species were present in small numbers by the second week of May. Large influxes of King Eiders occurred in mid-May of both years and large numbers were present until early June in 1976 and late June in 1978. The latter difference may have been due to the severe ice-conditions in 1978. Peak numbers of King Eiders recorded during spring surveys were close to 20,000 in eastern Lancaster Sound in early June 1976 and about 35,000 in northwest Baffin Bay and eastern Lancaster Sound in late May 1978. The main influx of Common Eiders occurred in late May and early June of both 1976 and 1978.

During the period of peak spring migration both species of eiders were found almost exclusively along ice-edges and coasts. In eastern Lancaster Sound in 1976, eiders (both King and Common) concentrated along the south coast of Devon Island between Cape Sherard and Cape Warrender. King Eiders also occurred in substantial numbers along the north coasts of Bylot Island and the Brodeur Peninsula of Baffin Island. In 1978, eider concentrations occurred along coasts and ice-edges at Coburg Island and along the east and south-east coasts of Devon Island.

Several movements of eiders through eastern Lancaster Sound and northwest Baffin Bay occur after the spring migration. A relatively small movement of predominantly male King Eiders occurred in early July 1976. These males were presumably undertaking a pre-moult migration to known moulting areas along the west coast of Greenland. In mid-July 1976, a movement of male Common Eiders was evident but it was less pronounced than the previous moult migration of King Eiders. In early to mid-August, a major movement of female eiders occurred in both 1976 and 1978. These birds were noted flying east along the north coast of Baffin Island and south through Navy Board Inlet in 1976 and along the north and east coasts of Bylot Island in 1978. Although these females could not be identified to species, available evidence suggests that they were probably King Eiders (Johnson _et al._, 1976a).

The number of eiders remaining in the respective study areas in 1976 and 1978 after mid-August were fairly low (a few thousand). Many of these eiders were still present in mid-October of 1978.

Eiders are subject to non-breeding in years with late thaws (see Palmer, 1976b for review). In such years, very few young are produced. Eiders can also suffer mortality in spring when shallow marine feeding areas and/or

marine resting areas remain ice-covered (Barry, 1968; Palmer, 1976b). The average clutch size for Common Eiders is about 4 eggs and for King Eiders about 5 eggs (Bellrose, 1976). Lamothe (1973) found that breeding success for King Eiders on Bathurst Island could be very low even in years with good weather conditions. Thus, eiders may have only a limited potential to recoup human-induced losses to their populations.

4.2.6.6 Glaucous Gull

The Glaucous Gull (*Larus hyperboreus*) is a large circumpolar gull that is a common nesting bird throughout the Canadian Arctic (Godfrey, 1966). It nests in small colonies (up to 200-300 pairs) on and near coasts at scattered locations throughout the arctic archipelago (see Tuck and Lemieux, 1959; Davis *et al*., 1974; Nettleship, 1974; B.C. Research, 1975; Brown *et al*., 1975; Alliston *et al*., 1976; McLaren and Renaud, 1977; LGL Ltd., unpubl. data). The migration routes and wintering areas of the Glaucous Gulls from Lancaster Sound are unknown.

Glaucous Gulls were widespread along coasts in eastern Lancaster Sound in 1976 and in the northwest Baffin Bay-eastern Lancaster Sound area in 1978. They are present in these areas from early May until October. The spring migration is gradual and continues throughout May and early June. Distribution is fairly uniform in spring although concentrations were found near Coburg Island and along the Pond Inlet ice-edge.

In 1976, the numbers of Glaucous Gulls increased in July as more sub-adult non-breeding birds returned to the area. In both years, the numbers increased further in August and September. In 1976, an estimated 2500 Glaucous Gulls were present in eastern Lancaster Sound in early September. Peak numbers (over 6500 counted) occurred in late September in the northwest Baffin Bay-eastern Lancaster Sound study area in 1978. The increases in August and September were due to nesting and fledgling gulls moving into coastal areas and to the arrival of migrant gulls from areas to the west and north. Major fall concentrations occurred along the southeast coast of Ellesmere Island and along the east and southeast coasts of Devon Island.

4.2.6.7 Ivory Gull

The Ivory Gull (*Pagophila eburnea*) is a small circumpolar gull; it remains in arctic environments throughout the winter when the birds forage along leads and around

floating pack ice (Godfrey, 1966). The Ivory Gull may be the rarest of the gulls that regularly nest in the Canadian Arctic. Currently occupied colonies in Canada are on Seymour Island, north of Bathurst Island (about 200 nesting pairs--MacDonald, 1976) and on southeastern Ellesmere Island (5 small colonies--D.N. Nettleship, pers. comm.).

Johnson _et al._, (1976a) recorded 257 Ivory Gulls during the surveys in 1976. Three individuals were recorded in May but substantial numbers were not present until mid-June. The numbers present in eastern Lancaster Sound peaked in July and late August and the species was still present at the end of September. Most Ivory Gulls were found in the northern half of Lancaster Sound. From June through early August, they were widespread but primarily coastal in distribution. In mid-August to late September of 1976, Ivory Gulls were less common along coasts but more common in nearshore and offshore waters.

In 1976, Ivory Gulls were most common along the east coast of Devon Island, between Philpots Island and Cape Sherard, where they fed in waters along and off the 'marine fronts' of large glaciers. The breeding status of the Ivory Gulls observed in eastern Lancaster Sound is unknown since there are no known colonies in the area.

Ivory Gulls were uncommon in May of 1978 as well as 1976. Small numbers were present from late May through July. Numbers increased in August and remained high in September. Over 550 were recorded in late September of 1978. The distribution of Ivory Gulls was not uniform. In spring 1978, they were most common along the Jones Sound and Pond Inlet ice-edges. In the summer and fall of 1978, the waters off the coasts of Devon Island and southeast Ellesmere Island were most important to Ivory Gulls. The southeast coastal waters of Devon Island were also important in 1976.

4.2.6.8 Black-legged Kittiwake

The Black-legged Kittiwake (_Rissa tridactyla_) is a small holarctic breeding gull that winters pelagically in both the Atlantic and Pacific Oceans. The population that breeds in the Lancaster Sound area probably winters off the west and south coasts of Greenland and in the North Atlantic off the coasts of Labrador, Newfoundland, the Maritime provinces and northeastern United States (Godfrey, 1966; Brown _et al._, 1975). Litle is known of the migration routes between the summering and wintering areas although the birds surely follow Baffin Bay waters (Brown _et al._, 1975). The locations and sizes of known colonies of kittiwakes in the

northwestern Baffin Bay-Lancaster Sound area are shown in Figure 4-53. The major colonies in the area are near Cape Hay, Bylot Island (50,000 pairs in 1957, Tuck and Lemieux, 1959), Prince Leopold Island (29,000 pairs in 1975, Nettleship, 1977) and Coburg Island (probably larger than Cape Hay colony, D.N. Nettleship and S.R. Johnson, unpubl. data). A colony of 100 to 1000 pairs on the Wollaston Islands (Brown et al., 1975) contained only about 30 non-breeding birds in August 1976 (Johnson et al., 1976a) and no birds in early September 1978 (M. Bradstreet, unpubl. data).

A few Black-legged Kittiwakes return to the study area in early May but the main influx occurred in late May and early June in both 1976 and 1978. In eastern Lancaster Sound in 1976, this influx consisted of migrants moving through the offshore waters of the Sound to colonies farther west and birds returning to the colony at Cape Hay. Similar movements over the offshore waters of northwest Baffin Bay are undoubtedly undertaken by the kittiwakes nesting on Coburg Island.

From mid-June through mid-August of 1976 the numbers of kittiwakes in eastern Lancaster Sound remained relatively constant. The major concentrations occurred near the Cape Hay colony and along the ice-edge across Navy Board Inlet (Figures 4-54 and 4-55). Similar concentrations were present in waters adjacent to the Coburg Island colony in 1978.

In 1976, fledged young kittiwakes were first noted in eastern Lancaster Sound on 31 August and no young remained on the eastern part of the Cape Hay colony on 4 September. Nettleship and Gaston (1978) found that about one third of the young kittiwakes had fledged from Prince Leopold Island by 29 August and most had left that colony by 11 September. Kittiwakes began to disperse away from the Cape Hay colony as the young fledged. In mid-August, kittiwakes had been highly concentrated within about 25 km of the colony (Figure 4-56). By early September, kittiwakes were widely distributed along coasts in eastern Lancaster Sound, including significant concentrations along the coast of Devon Island (Figure 4-57). The estimated number of kittiwakes present in eastern Lancaster Sound on 5-7 September was about 29,000 birds compared with about 25,000 in early August.

A major influx of kittiwakes was noted on 12-13 September 1976 when an estimated 45,000 birds were present. Most of the increases from the 5-7 September survey was due to an additional 13,000 birds in offshore waters (over 7 k from shore) on 12-13 September. The increased densities

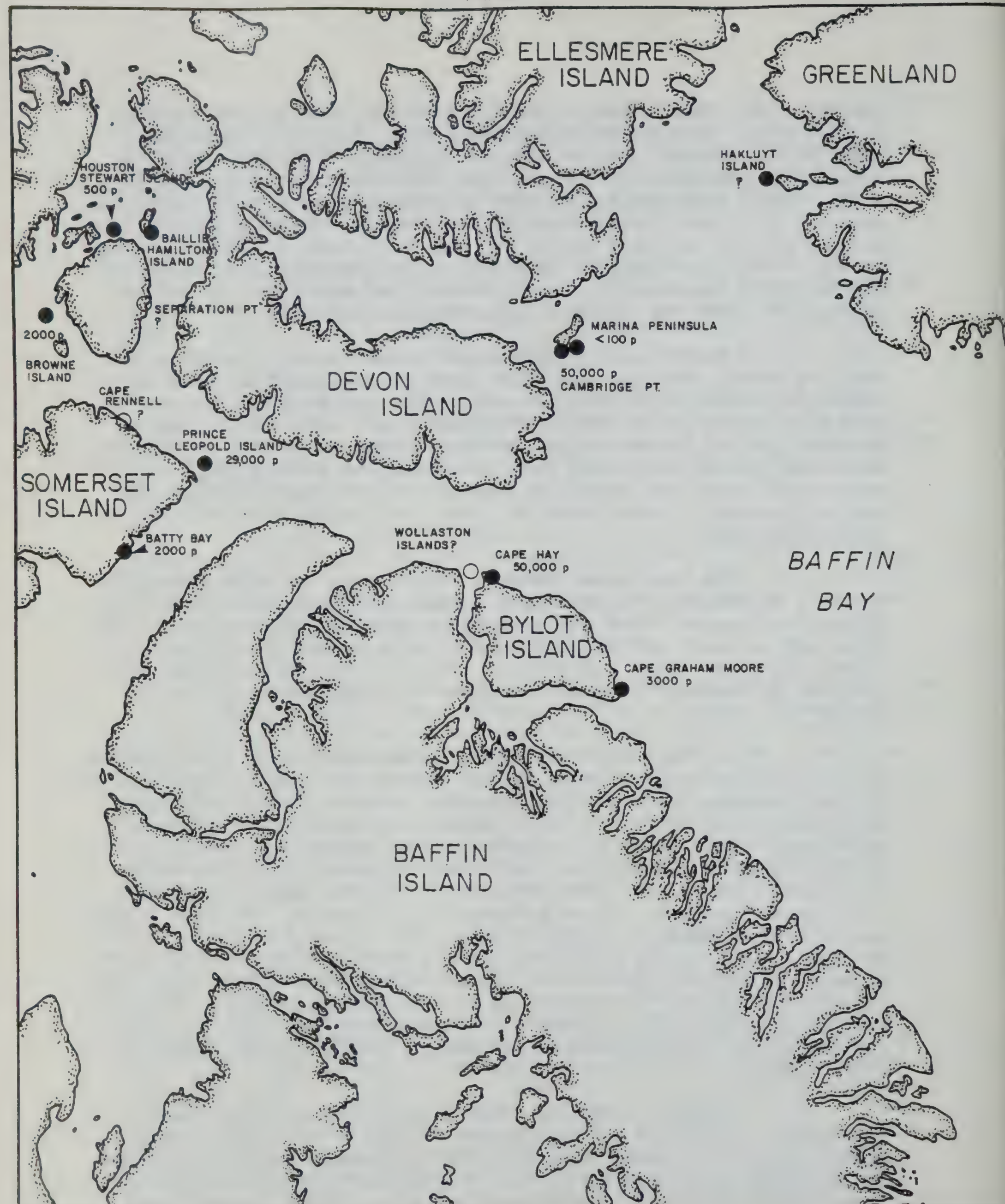
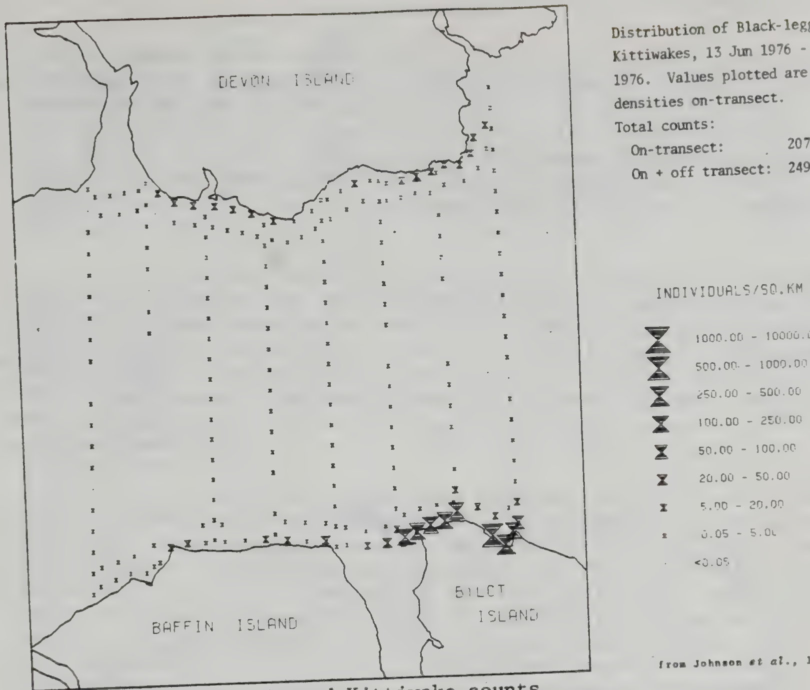


Figure 4-53

Locations of Black-legged Kittiwake Colonies in the Lancaster Sound--NW Baffin Bay Area. Data are from Brown *et al.* (1975), Alliston *et al.* (1976), Nettleship and Gaston (1978) and LGL Ltd. (unpublished).



Distribution of Black-legged Kittiwakes, 13 Jun 1976 - 13 Jul 1976. Values plotted are mean densities on-transect.

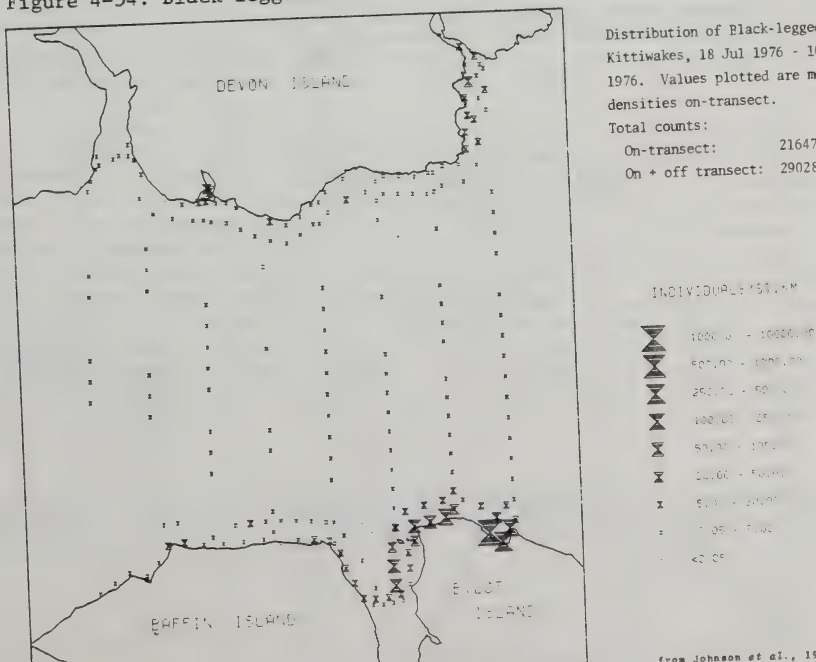
Total counts:

On-transect: 20773

On + off transect: 24983

from Johnson et al., 1976a.

Figure 4-54: Black-legged Kittiwake counts.



Distribution of Black-legged Kittiwakes, 18 Jul 1976 - 10 Aug 1976. Values plotted are mean densities on-transect.

Total counts:

On-transect: 21647

On + off transect: 29028

from Johnson et al., 1976a.

Figure 4-55: Black-legged Kittiwake counts.

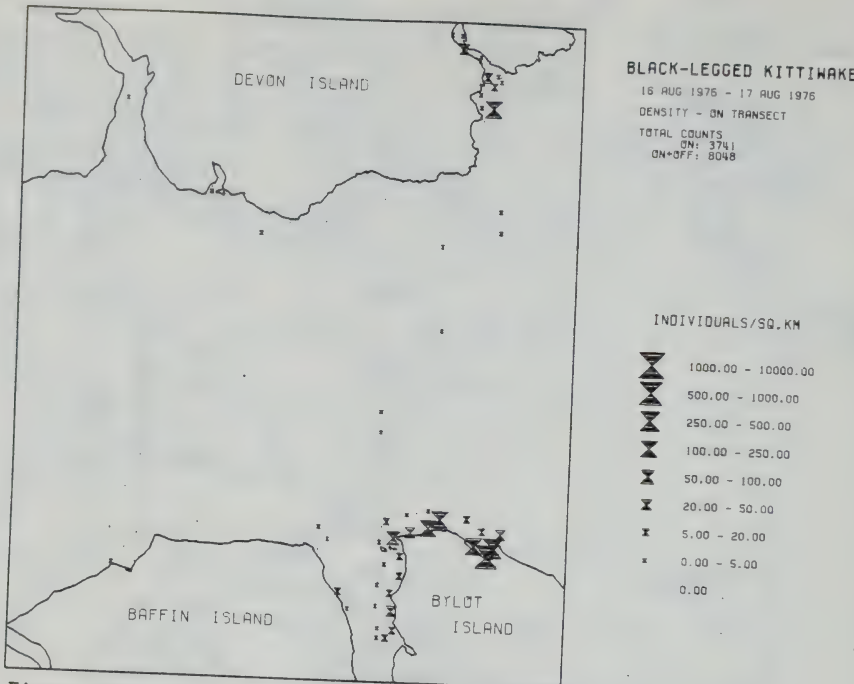


Figure 4-56: Black-legged Kittiwake counts.

from Johnson *et al.*, 1976a.

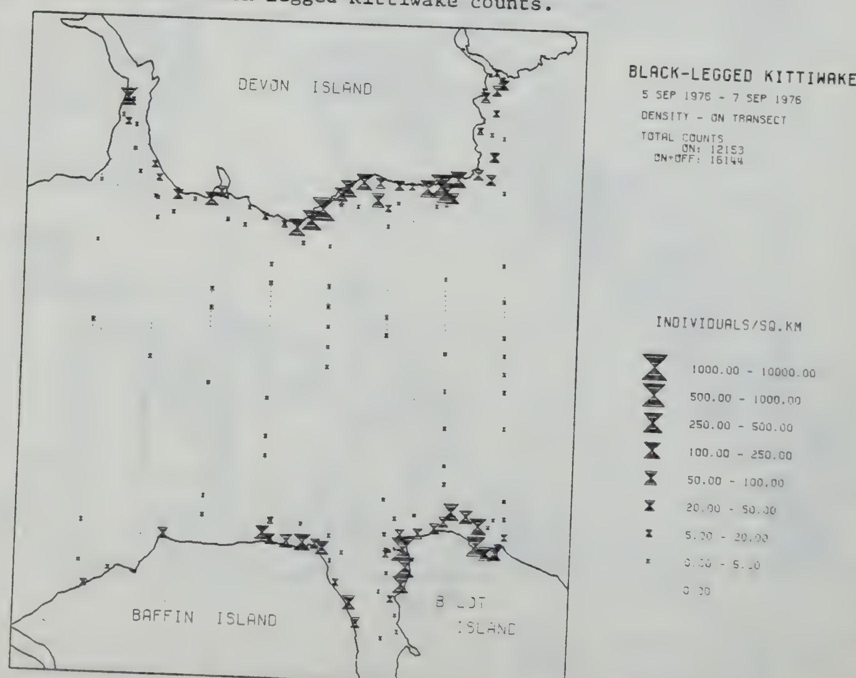


Figure 4-57: Black-legged Kittiwake counts.

from Johnson *et al.*, 1976a.

along coasts in the west part of the study area and in offshore waters suggest that a major influx of birds from the colonies to the west had occurred (Figure 4-58). This is corraborated by the results of Nettleship and Gaston (1978), who found that the numbers of kittiwakes in western Lancaster Sound and eastern Barrow Strait declined from 28,500 on 29 August and 27,000 on 11 September to 14,000 on 12 September, 1976.

In 1976, numbers of kittiwakes in eastern Lancaster Sound declined after mid-September but the species was still widespread and common at the end of September when surveys terminated (Figure 4-59). In 1978, the numbers of kittiwakes remained high in late September and very large concentrations were found along the east coast of Devon Island. Few kittiwakes remained in the northwest Baffin Bay area by mid-October 1978.

At Cape Hay, Tuck and Lemieux (1959) found that clutch sizes of kittiwakes varied from one to three eggs in 1957 and that nests contained an average of 1.2 young by mid-August. Nettleship and Gaston (1978) found that an average of slightly less than one fledgling was produced per pair at Prince Leopold Island in 1976. There is no information on the rate of survival of individuals from the time of fledging to the time of first breeding for kittiwakes from arctic colonies. Coulson (1966) found that kittiwakes in Great Britain first nested at 3 to 4 years of age for females and 4 to 5 years of age for males. Coulson and Wooler (1976) determined that mean life expectancy of kittiwakes was 9 to 11 years in temperate areas.

The distribution of the non-breeding one-, two- and three-year old kittiwakes is not well known. The two- and three-year olds are similar to breeding adults in plumage and cannot be distinguished during aerial or ship-based surveys. Thus, the presence and distribution of these non-breeders in eastern Lancaster Sound has not been documented. On the other hand, yearlings can be distinguished from older birds and it was found that yearlings returned to eastern Lancaster Sound in late August of 1957 (Tuck and Lemieux, 1959), late August of 1976 (Johnson *et al*., 1976a) and mid-August of 1978 (M. Bradstreet, unpubl. data). The numbers and distribution of these yearlings in September are not known.

4.2.6.9 Arctic Tern

The Arctic Tern (*Sterna paradisaea*) nests throughout Arctic Canada; it winters in the southern hemisphere

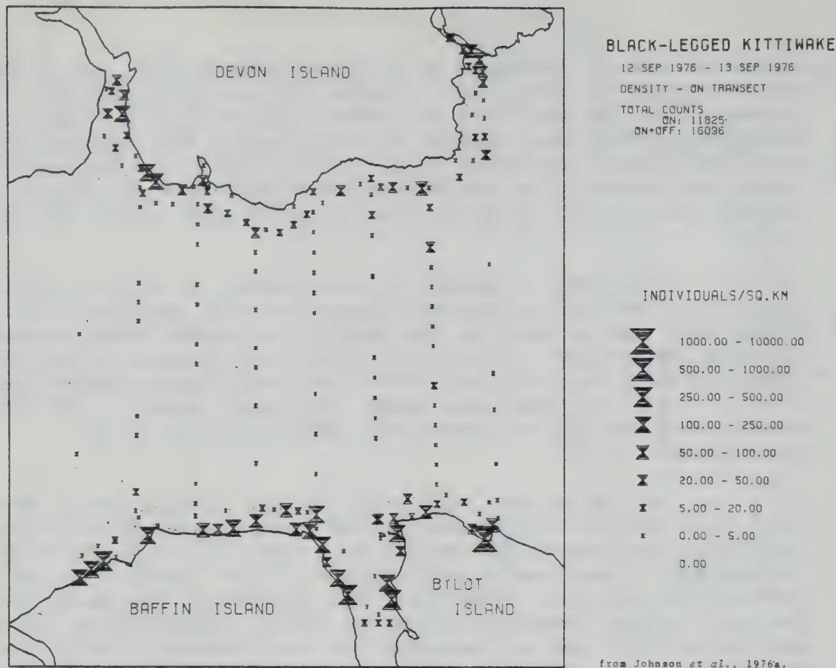


Figure 4-58: Black-legged Kittiwake.

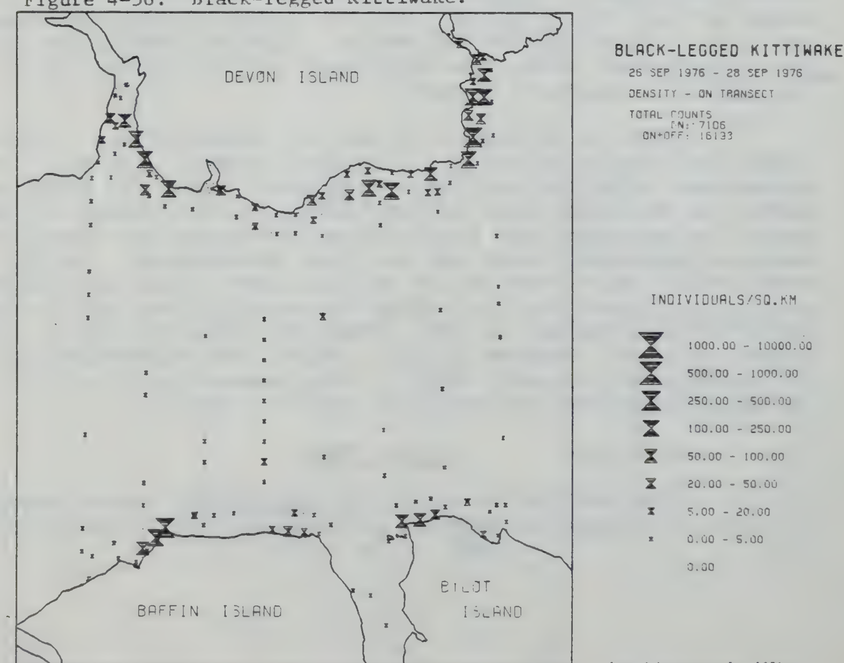


Figure 4-59: Black-legged Kittiwake.

including the Antarctic (Godfrey, 1966; Salomonsen, 1967). The species was moderately common in eastern Lancaster Sound in 1976 and in the larger study area surveyed in 1978.

Arctic Terns arrived in the study area in mid-June of both 1976 and 1978 and the numbers increased until late June and early July. Many of the terns seen from mid-June to mid-July were in offshore waters; these birds were probably migrating to other areas further west. Concentrations in spring 1978 occurred along the north and east coasts of Bylot Island and along the Jones Sound ice-edge. From mid-July onward, terns occurred primarily in coastal and nearshore waters of southeast Devon Island and along the west and south coasts of Bylot Island. By late August and early September 1976, terns were concentrated almost exclusively in Bethune Inlet at the southwest side of Philpots Island. In 1978, the east and west coasts of Bylot Island were also important. Arctic Terns began leaving the study area in early September and none were recorded after late September.

4.2.6.10 Thick-billed Murre

The Thick-billed Murre (*Uria lomvia*) nests on coasts and islands in the Arctic of North America and Eurasia. In Canada, small numbers breed as far south as the Gulf of St. Lawrence but the majority nest adjacent to arctic waters (Godfrey, 1966; Brown *et al.*, 1975). Four major colonies of Thick-billed Murres are found in the eastern Canadian high Arctic (Figure 4-60). The largest is near Cape Hay, on northern Bylot Island; it was estimated to contain 400,000 pairs in 1957 (Tuck, 1960) but the numbers have recently declined significantly (D. Nettleship, Can. Wildl. Serv., pers. comm.). Approximately 86,000 pairs nest at Prince Leopold Island in western Lancaster Sound (Nettleship and Gaston, 1978) and about 20,000 pairs nest at Cape Graham Moore on SE Bylot Island (Brown *et al.*, 1975). A large colony is present on the south end of Coburg Island off the entrance to Jones Sound. This colony has not yet been accurately censused but was estimated to contain about 200,000 pairs in 1973 (Brown *et al.*, 1975). In northwest Greenland, murres nest at Hukluyt Island, Carey Islands, Saunders Island and at Agpat and Igsivigsoq, Parker Snow Bay (Brown *et al.*, 1975). In addition to nesting birds, non-breeders and pre-breeders also occur in northern Baffin Bay and in Lancaster Sound during the open water period.

Thick-billed Murres from Lancaster Sound winter along the west coast of Greenland whereas many of the murres that nest in NW Greenland winter in waters off Newfoundland (Tuck, 1960; Salomonsen, 1972). Tuck (1971) suggested that

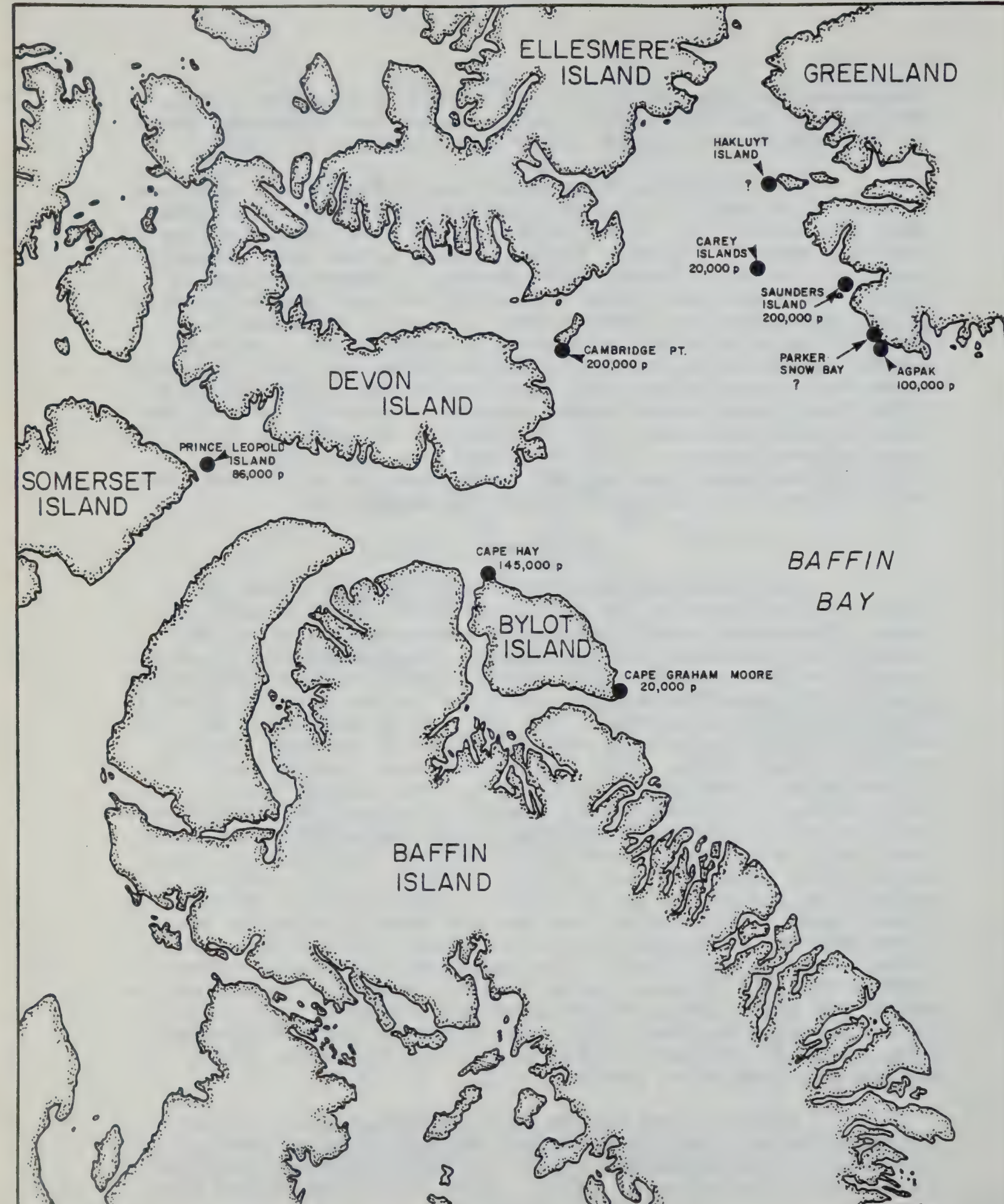


Figure 4-60

Locations of Thick-billed Murre Colonies in the Lancaster Sound--NW Baffin Bay Area. Data are from Tuck (1960), Brown *et al.* (1975) and Nettleship and Gaston (1978).

adult murres tended to winter further north than did one and two-year olds. Nothing is known of spring migration routes through Baffin Bay; the autumn migration is thought to follow the southward flowing current in central and western Baffin Bay. Analysis of the very large volume of data on murres in northwest Baffin Bay-eastern Lancaster Sound collected in 1978 has not been completed. Therefore this account is restricted to the findings from eastern Lancaster Sound in 1976 (Norlands Ltd., 1978).

Thick-billed Murres were common in Lancaster Sound during 1976. Murres were not recorded in eastern Lancaster Sound at the beginning of May, but a large influx occurred between 3 and 9 May. About 95,000 murres were estimated to be present in leads and cracks in the offshore pack-ice on 9-11 May. These birds were in the western two thirds of the study area and may have been migrating west to Prince Leopold Island.

The number of Thick-billed Murres peaked on 16-20 May when about 180,000 were estimated to be present (Figure 4-61). Again, most (165,000) of these birds were offshore in the restricted open water among ice floes. D. Nettleship (pers. comm.) noted a major influx of murres at the Prince Leopold Island colony on 22-23 May 1976. The results of the 23-24 May survey in eastern Lancaster Sound indicate that murres were still passing through to the west, but numbers had begun to build up near the Cape Hay colony (Figure 4-62). An estimated 130,000 murres were present during this survey. The number of murres declined to fewer than 100,000 in late May, but an influx in early June (estimated 130,000+) apparently involved additional birds returning to the Cape Hay colony (Figure 4-63).

The number of murres recorded from mid-June through mid-August fluctuated markedly, but these fluctuations were probably due to daily and seasonal changes in attendance patterns at the Cape Hay colony and variations in weather conditions. Murres were concentrated in waters near the Cape Hay colony from mid-June through mid-July, but large numbers were still present and widely distributed in offshore waters (Figure 4-64); an estimated 92,000 were present in waters more than 1.4 km from shore on 20-21 June. In the mid-July to mid-August period the distribution of murres became more concentrated near Cape Hay and northeastern Navy Board Inlet (Figure 4-65).

Most Thick-billed Murre eggs at high arctic colonies have hatched by late July or early August (Tuck, 1960; Nettleship, 1977). During the chick-rearing phase, adult

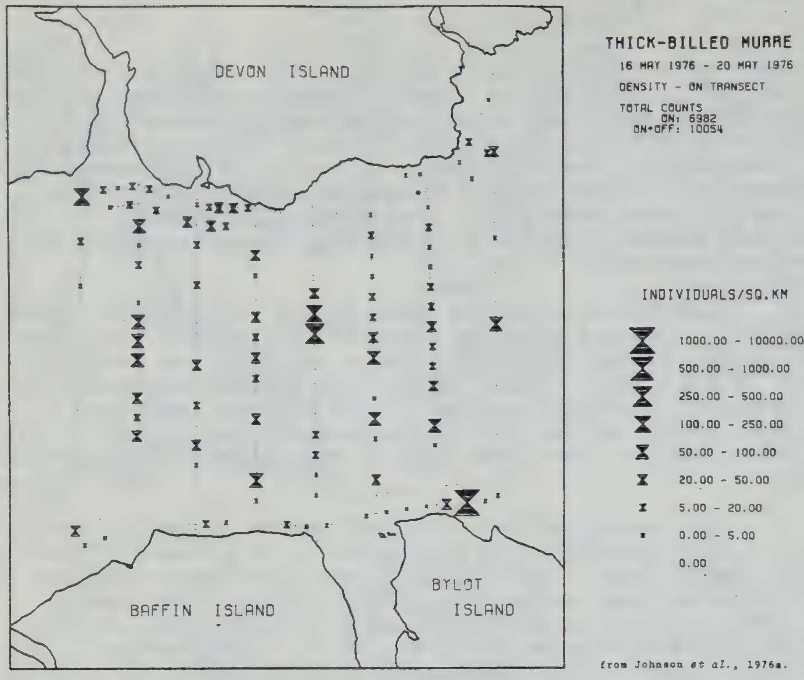


Figure 4-61: Thick-billed Murre.

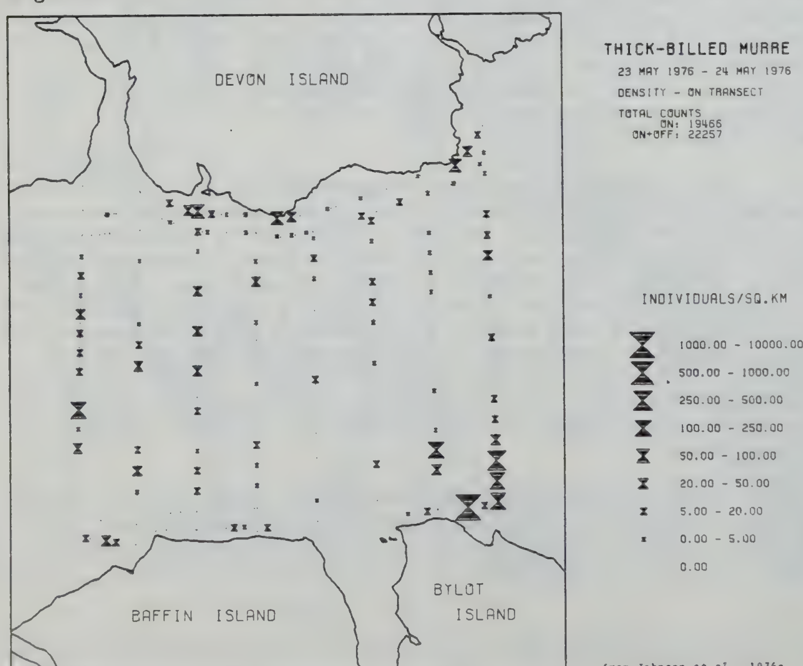
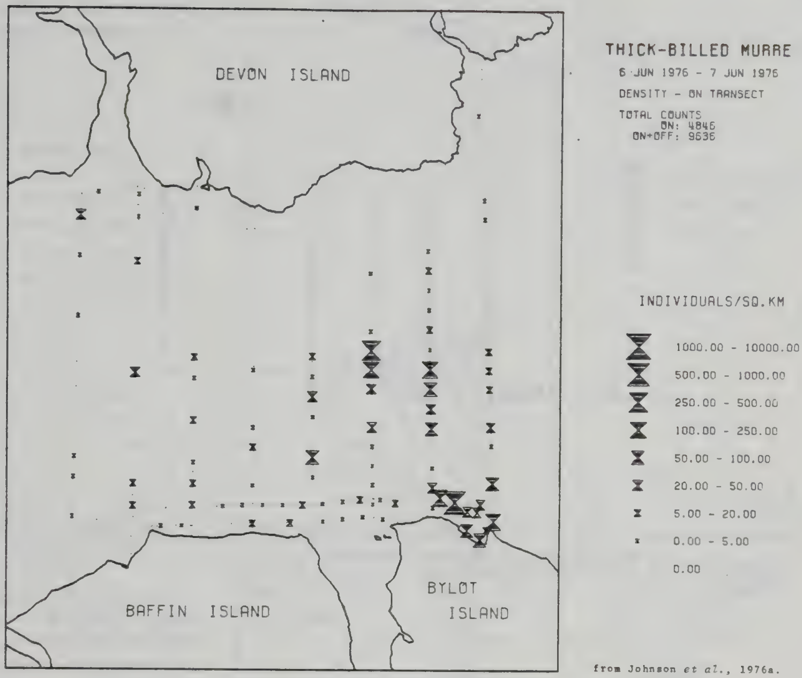
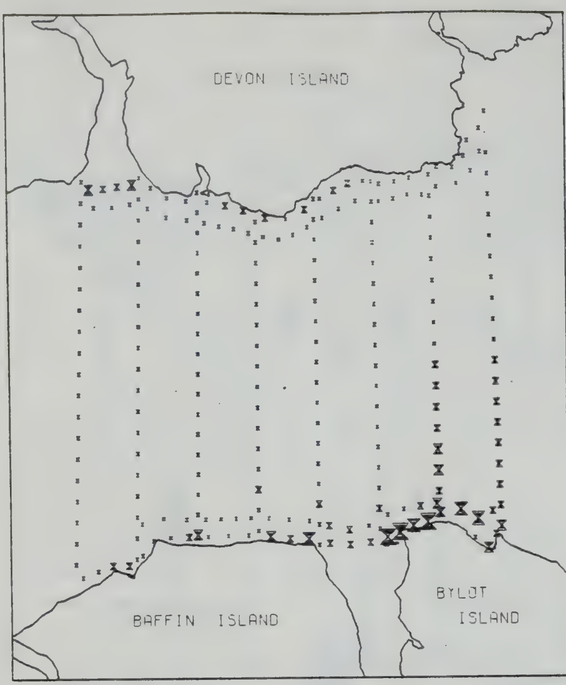


Figure 4-62: Thick-billed Murre.



from Johnson *et al.*, 1976a.

Figure 4-63: Thick-billed Murre counts.



Distribution of Thick-billed Murres, 13 Jun 1976 - 13 Jul 1976. Values plotted are mean densities on-transect.

Total counts:

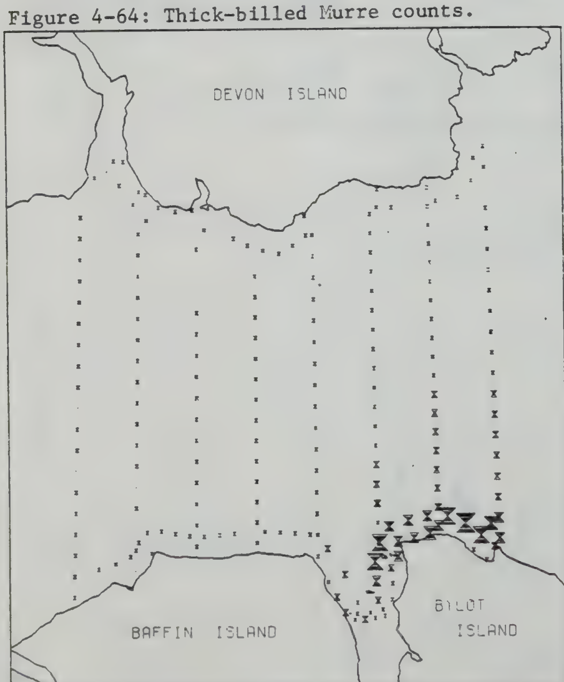
On-transect:	15882
On + off transect:	26965

INDIVIDUALS/SQ.KM

1000.00 - 10000.00
500.00 - 1000.00
250.00 - 500.00
100.00 - 250.00
50.00 - 100.00
20.00 - 50.00
5.00 - 20.00
0.05 - 5.00
<0.05

from Johnson *et al.*, 1976a.

Figure 4-64: Thick-billed Murre counts.



Distribution of Thick-billed Murres, 18 Jul 1976 - 10 Aug 1976. Values plotted are mean densities on-transect.

Total counts:

On-transect:	13734
On + off transect:	23421

INDIVIDUALS/SQ.KM

1000.00 - 10000.00
500.00 - 1000.00
250.00 - 500.00
100.00 - 250.00
50.00 - 100.00
20.00 - 50.00
5.00 - 20.00
0.05 - 5.00
<0.05

from Johnson *et al.*, 1976a.

Figure 4-65: Thick-billed Murre counts

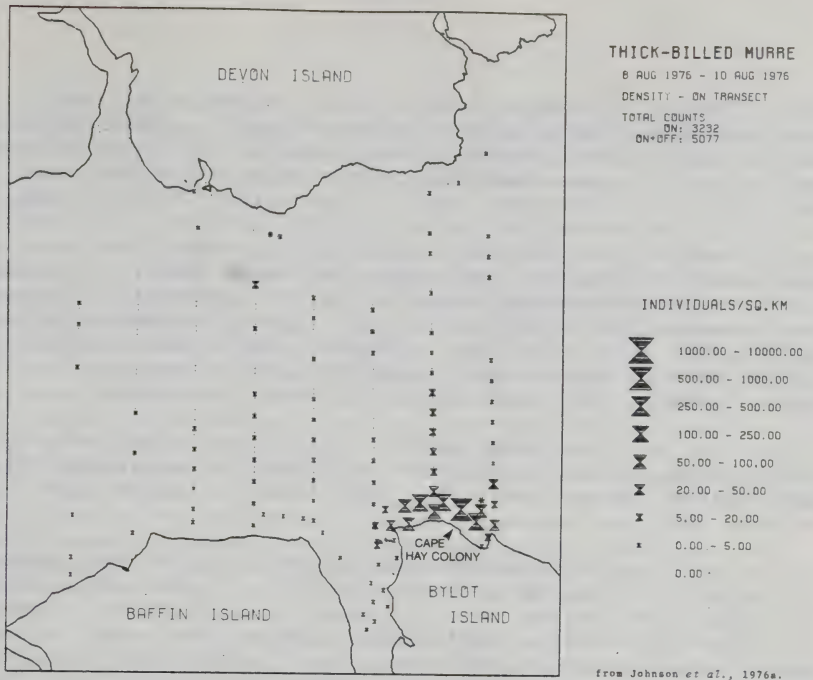


Figure 4-66: Thick-billed Murre counts.

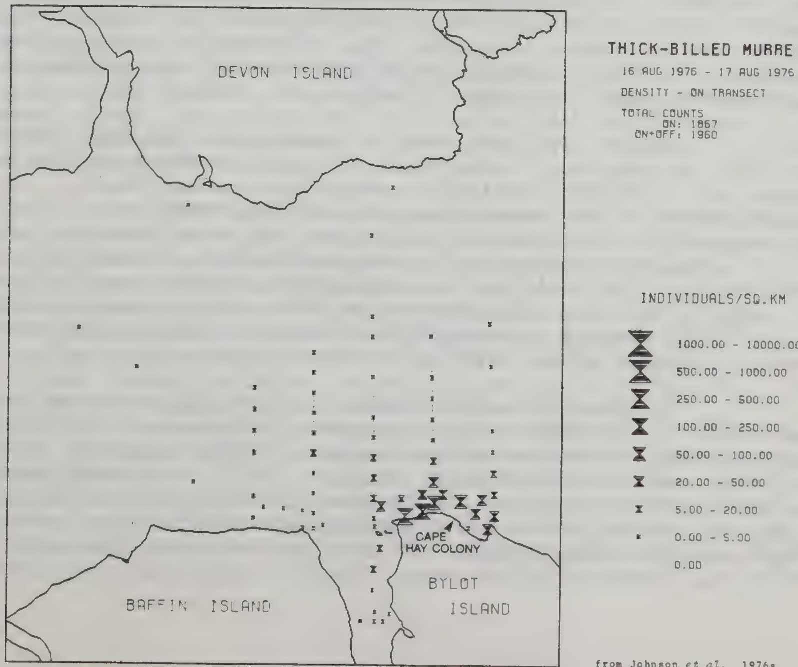


Figure 4-67: Thick-billed Murre counts.

murres became even more concentrated in waters adjacent to the Cape Hay colony (Figures 4-66 and 4-67). Most murres were present within about 30 km of the colony in mid-August and only a few were recorded in the western and northern parts of the study area; many of the latter non-breeding birds (M. Bradstreet in Johnson et al., 1976a). It should be noted that survey coverage extended less than 30 km east of the colony and murres feeding in northwest Baffin Bay would not have been recorded. Nettleship and Gaston (1978) suggest that some murres at Prince Leopold Island foraged up to 110 km from the colony on 2 and 6 August, 1976, but 63% and 48% of the murres seen during the surveys conducted on these two days, respectively, were within 32 km of the colony.

In 1978, murre concentrations were associated primarily with the major colonies at Coburg Island, Cape Hay and Cape Graham Moore. Ice-edges near these colonies were heavily used.

The first observations of mure chicks were made on 29 August in 1976 and 23 August in 1978. Tuck (1960) found that the first chicks left the Cape Hay colony on 15 August in 1957. Nettleship (1977) found that chicks began to leave the Prince Leopold Island colony on 12 August and that virtually all chicks had left the colony by 3 September in 1975. R.G.B. Brown (in Nettleship and Gaston, 1978) found many fledged young a few km east of Prince Leopold Island on 17-19 August 1976. Coincident with the departure of young from Cape Hay in 1976 was the virtual abandonment by murres of the waters near Cape Hay in late August and September.

During the last week of August and during September in 1976, murres were widespread in small numbers in the near-shore and offshore waters of eastern Lancaster Sound. About 40% of these birds were recorded as being members of adult/young pairs. It should be noted that at this time the young are flightless and the adults are either flightless or reluctant to fly (Tuck, 1960); consequently, murres are difficult to detect during aerial surveys at this time. Aerial surveys during this period are useful for determining general distribution patterns, but not for numerical estimates.

It is not known whether the family groups of murres recorded in late August and September originated from the Cape Hay colony or the Prince Leopold Island colony. Strong surface currents (1.8 km/hr; Collin, 1962) flow east past Cape Hay and it is possible that most family groups from the Cape Hay colony follow this current into Baffin Bay soon after leaving the colony. If this is the case, then most of the family groups in Lancaster Sound in September are proba-

bly birds that are migrating (i.e., swimming) eastward through Lancaster Sound from Prince Leopold Island. Virtually all Thick-billed Murres had left eastern Lancaster Sound by mid-September. Fewer than 100 were present on 26-28 September, 1976.

The age of first nesting for Thick-billed Murres is unknown, but that for the Common Murre in Britain is 5 years (Birkhead and Hudson, 1977). The effective fertility of a nesting pair is one egg. In 1975, fledging success of Thick-billed Murres at Prince Leopold Island was high; Nettleship (1977) reported that 0.8 chicks fledged for every egg laid. The mean life expectancy of Common Murres is about 16 years (Birkhead, 1974) and mortality rates are 62% during the first year of life, 23% per year for the next two years and 6% per year thereafter (Mead, 1974). There are no comparable estimates for Thick-billed Murres, but if estimates are similar to those for Common Murres, it is expected that the annual recruitment of birds into the breeding population is low. Therefore, the ability of murres to recover from large-scale reductions of their populations would be poor.

Murre chicks accompanied by one of the adults (almost always the male--M. Bradstreet, unpubl. data), leave the colony before the chicks can fly and undertake at least part of their southward migration by swimming. The accompanying adults become flightless or are unwilling to fly and at this time murres are potentially very susceptible to human-induced impacts. The distribution of pre-breeding (immature) Thick-billed Murres is unknown. Tuck (1960) found that some Common Murres may prospect colonies during their second summer but that most second year and all first year birds summer south of breeding areas.

Thick-billed Murres from the Lancaster Sound area have recently been declining in numbers--probably largely due to their being inadvertently taken in drift-nets used in the salmon fishery off West Greenland and their being hunted on their wintering ground off West Greenland. Tull et al. (1972) estimated the annual mortality in the salmon fishery to be 540,000 birds for the years 1969 to 1971. Christensen and Lear (cited in Evans and Waterstan, 1976) indicate a rather lower estimated kill in 1970 (350,000) and 1971 (240,000); and a kill of about 207,000 birds in 1972 (Christensen and Lear, 1977). The kill is expected to decrease since the salmon fishery is now much reduced (Evans and Waterstan, 1978). Salomonsen (1970) concluded that yearly hunting mortality in West Greenland was 750,000 birds, of which about 160,000 were from the Lancaster Sound population.

Combined, these figures indicate an existing substantial impact on the Lancaster Sound/Baffin Bay murre population.

4.2.6.11 Dovekie

The Dovekie (*Alle alle*) is a small auk that nests in very large numbers along the west coast of Greenland north of 76°N (Salomonsen, 1950; Brown *et al*., 1975)(Figure 4-68). Dovekies are not known to nest in Canada. The Dovekie winters south of the arctic ice pack from southwestern Greenland to northeastern United States; most of the population remains in subarctic and boreal waters as far north as there is extensive open water (Salomonsen, 1950; Godfrey, 1966). The spring migration route through Baffin Bay is unknown; in autumn Dovekies follow the Baffin Bay Current south through central and western Baffin Bay (Brown *et al*., 1975).

In 1976, Dovekies were first recorded in eastern Lancaster Sound on 9-11 May when small numbers (about 200) were estimated to be present. A major influx into eastern Lancaster Sound occurred between 11 and 16 May. Over 1,000,000 Dovekies were estimated in the area on 16-20 May and over 1,600,000 were estimated for 23-24 May. These birds were virtually all in leads and cracks in the offshore pack-ice over 7 km from landfast ice (Figure 4-69 and 4-70). Dovekies left eastern Lancaster Sound as abruptly as they arrived; only one individual was recorded during the 30 May - 1 June 1976 survey. Presumably, the Dovekies had moved northeast to their colonies in Greenland.

In May 1978, very large numbers of Dovekies were again recorded off the entrance to Lancaster Sound. Final estimates of numbers are not yet available. From June through September 1976, Dovekies were recorded regularly in small numbers in offshore waters. The maximum estimates during this period were about 11,000 birds in late June and in mid-September. However, during the open water season Dovekies occurred in small groups that tended to dive rather than flush ahead of the aircraft. They were extremely inconspicuous, especially during even moderately rough sea conditions. Shipboard observations indicated that Dovekies were much more common during open water periods than was indicated by the results of the aerial surveys (Johnson *et al*., 1976a).

Dovekies present in eastern Lancaster Sound during June and July 1976 were probably non-breeding birds. Young Dovekies leave the colonies in Greenland during the latter half of August and the colonies are completely deserted by 1

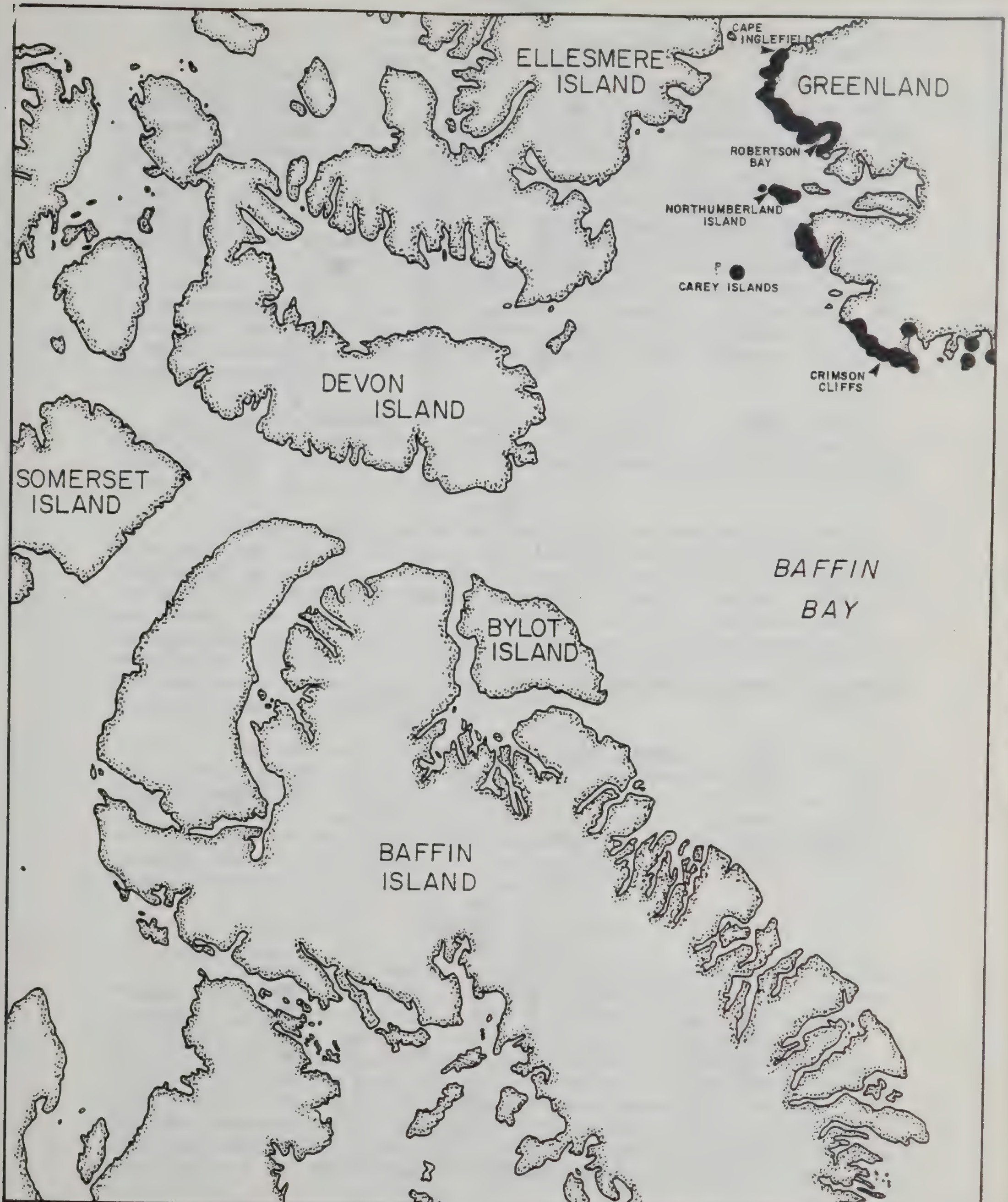


Figure 4-68

Locations of Dovekie breeding areas in NW Baffin Bay. Breeding areas are shown in black. Data are from Salomonsen (1950).

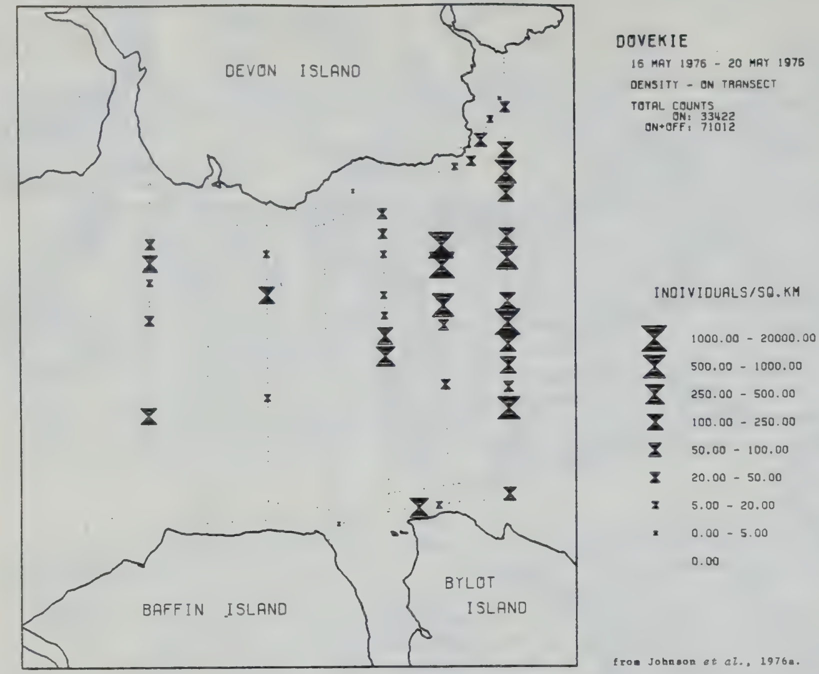


Figure 4-69: Dovekie counts.

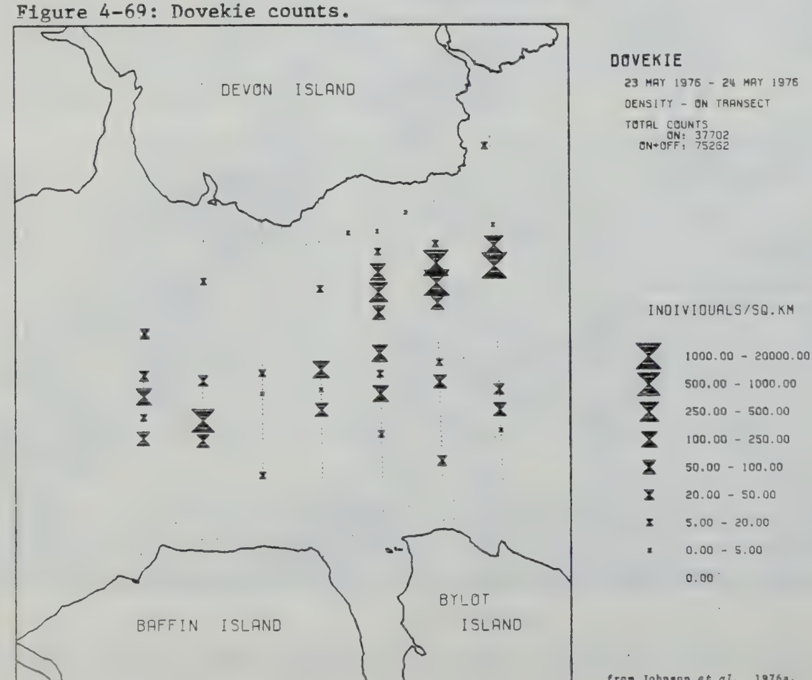


Figure 4-70: Dovekie counts.

September (Salomonsen, 1950). Thus, by September, the non-breeders in Lancaster Sound and adjacent areas may be joined by breeding adults and young of the year. The main fall migration from all high arctic waters in late September and October appears to follow the middle and west side of Baffin Bay; during fall migration, Dovekies apparently avoid the ice-free west Greenland coast (Salomonsen, 1950; Brown et al., 1975). The numbers of Dovekies entering eastern Lancaster Sound in 1976 during the fall migration could not be adequately assessed by aerial surveys. However, it is safe to conclude that the numbers of post-breeding Dovekies in the area in September 1976 did not approach the numbers recorded during the spring.

The findings of 1978 were similar; again, many fewer Dovekies used the study area in August and September than in May. Few Dovekies used the Jones Sound-Coburg Island area at any time of year.

The size of the northwest Greenland population of Dovekies is not well known; few colony counts are available (Brown et al., 1975). Freuchen and Salomonsen (1958) give an estimate of about 30 million birds at the northwest Greenland colonies, but the confidence limits for this estimate are undoubtedly very wide and no recent quantitative studies are available. Thus, it is difficult to assess the significance of the large numbers of Dovekies present in eastern Lancaster Sound/NW Baffin Bay in spring.

It is not known at what age Dovekies first breed nor is the mean life expectancy of this species known. Dovekies lay one egg (rarely two), but the breeding success of this species in arctic colonies is unknown. Given the lack of information on population parameters, it is impossible to assess the ability of this species to recover from potential human-induced reductions of its populations.

4.2.6.12 Black Guillemot

Black Guillemots (*Cepphus grylle*) nest along rocky coasts of eastern Canada from Ellesmere Island south to New Brunswick (Godfrey, 1966). The nesting range of the Black Guillemot in the eastern Canadian high Arctic is mapped in Figure 4-71. Guillemots nest in crevices and holes among rocks along coasts and cannot be accurately censused from aircraft. Some black Guillemots overwinter in the high Arctic in areas with permanent open water (Shortt and Peters, 1942; Snyder, 1957; LGL Ltd., unpubl. data) but most probably migrate out of Lancaster Sound (LGL Ltd., unpubl. data).

Figure 4-71

Breeding Range of the Black Guillemot in the Lancaster Sound--NW Baffin Bay Area. Breeding areas are shown in black. Data are from Salomonsen (1950), Brown *et al.* (1975), Alliston *et al.* (1976) and LGL Ltd. (unpublished).

Small numbers of Black Guillemots were present in the study area when surveys began at the beginning of May in 1976 and 1978. An influx of guillemots occurred in offshore waters in early May 1976; an estimated 6000 were present in leads and open water areas among the pack ice over 7 km from landfast ice-edges in eastern Lancaster Sound. The numbers estimated to be present in offshore waters remained high during the next two surveys (2600 on 16-20 May and 3900 on 23-24 May). Timing of spring migration was similar in 1978.

In 1976, the numbers of guillemots in coastal waters began to increase by 23-24 May when over 500 of the estimated total of 5000 birds were within 1.4 km of landfast ice-edges. Thereafter, the proportion in coastal waters continued to increase and by mid-June, few were recorded in offshore waters. Large numbers of Black Guillemots were found in the offshore pack ice of northwest Baffin Bay in May, June and July, 1978. Preliminary estimates indicate that at least 30,000 guillemots were present in these areas. However, in 1978, as in 1976, the highest densities were along ice-edges and, later in the season, coasts.

During the open water season, Black Guillemots were concentrated in coastal areas, primarily near known or suspected colonies.

Young Black Guillemots fledge during the last half of August and early September. The distribution of guillemots changed markedly during this period. No longer were the highest numbers recorded near nesting colonies; rather, they were scattered at coastal and offshore locations throughout the study area. Few guillemots remained in the study area by late September.

Uspenski (1958) found immature (first-year) birds dispersed along arctic coasts during the breeding season. G. Divoky (pers. comm.) found that first breeding occurred during the second, or more commonly, third years. Mean adult survival rate in a boreal population was 80.4% (Preston, 1968), which corresponds to a mean adult life expectancy of 4.6 years. G. Divoky (pers. comm.) found that annual nesting success varied from 0.6 to 1.6 chicks per nest in an arctic location.

4.2.6.13 Other Species

Several additional species of birds regularly use the waters of northwestern Baffin Bay and eastern Lancaster Sound but they are less common than the species treated in the preceding sections. These less common species include

Red-throated Loon, Red Phalarope, Pomarine Jaeger, Parasitic Jaeger, Long-tailed Jaeger, Thayer's Gull and Sabine's Gull. In addition, several species have been recorded in very small numbers in the study area. These include Yellow-billed Loon, Common Loon, Arctic Loon, Greater Shearwater, cormorant sp., Red-breasted Merganser, Skua, Greater Black-backed Gull and Common Puffin.

4.2.7 Marine Mammals

Information on the numbers and distributions of marine mammals in northwest Baffin Bay and eastern Lancaster Sound is reviewed in this section. The principal source of information is the series of studies conducted by Norlands Petroleums Ltd. in eastern Lancaster Sound in October 1975 and in 1976 (Stepney and Wooley, 1975; Johnson et al., 1976b; R.R.C.S. 1977; Norlands Ltd., 1978). A few preliminary results from the Petro-Canada studies in 1978 are included.

Eleven species of marine mammals have been recorded in the northwest Baffin Bay--Lancaster Sound area. Polar bears and ringed seals are permanent residents that occur in the area year-round. Bearded seals and walruses overwinter in small numbers in the high Arctic but most individuals are apparently migratory. Belugas, narwhals, bowhead whales and harp seals are regular migrants but they withdraw from the area in winter. Hooded seals, harbour seals and killer whales are uncommon in the northwest Baffin Bay--eastern Lancaster Sound area. The distribution, abundance and migrations of the common speices are summarized below. Information on food habits is presented in Section 4.2.9.2.

A map of the eastern high Arctic is included (Fig.4-72) to familiarize the reader with the locations of geographic areas mentioned in the following accounts.

4.2.7.1. Beluga (White Whale)

The beluga (*Delphinapterus leucas*) is a small, toothed whale that is holarctic in distribution. The size of the Canadian Arctic population of belugas is approximately 30,000 animals; the population using northwest Baffin Bay and Lancaster Sound is estimated to contain about 10,000 belugas (Sergeant and Brodie, 1975). A large population of belugas inhabits the west coast of Greenland with a substantial portion summering in the northern waters of Thule district; the status of this population is not well documented (Degerbol and Nielson, 1930; Kapel, 1975a).

The winter range of belugas from Lancaster Sound has not been determined. Sergeant and Brodie (1975) suggest that belugas may winter among the unconsolidated ice of Lancaster Sound or in the 'North Water' at the north end of Baffin Bay and southern Smith Sound. Recent surveys of the 'North Water' indicate that only a few hundred belugas overwinter there (LGL Ltd., unpubl. data). Most belugas evidently withdraw at least to southern Baffin Bay and Davis Strait during the winter. The timing and routes of the spring and

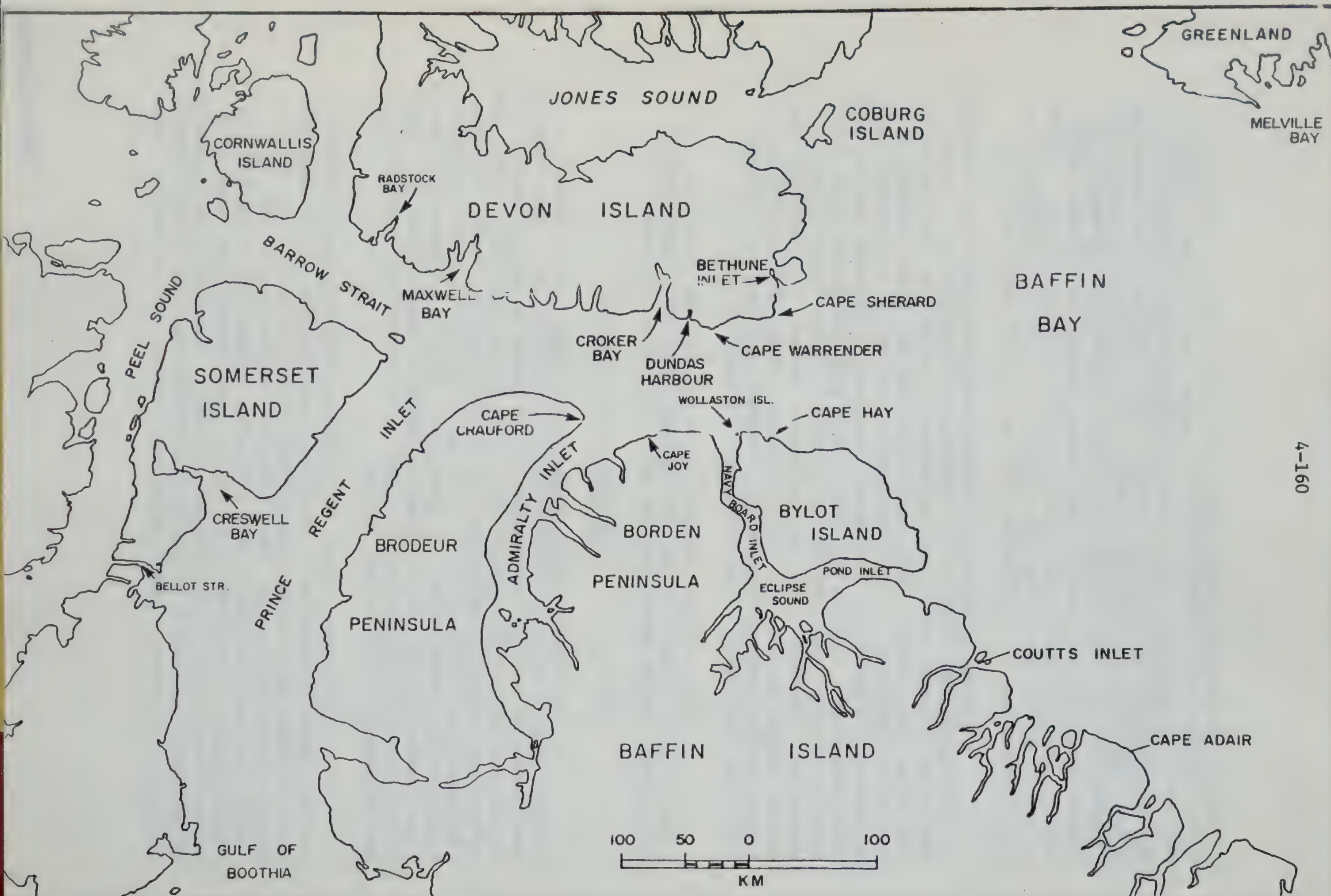


Figure 4-72: Eastern High Arctic place names.

autumn movements between northwest Baffin Bay and the wintering areas are unknown.

Small numbers of belugas enter Lancaster Sound in March and April in years (e.g., 1976) when ice conditions permit. In May 1976, belugas were concentrated along the coast of Devon Island (cf. Figure 4-73) with very few animals in offshore waters or along the southern margin of the sound. Numbers began to increase during late May but the main influx occurred from mid-June through mid-July. During the early part (late June) of this period substantial numbers were moving through nearshore and offshore waters with most travelling through the north part of the sound (Fig. 4-74). However, during the first half of July, the majority of belugas were in coastal waters, again near Devon Island (Figures 4-75 and 4-76).

The timing and pattern of spring migration by belugas into Lancaster Sound was very different in 1978. The unbroken fast-ice edge that stretched across the eastern entrance to Lancaster Sound prohibited entry to the Sound until mid-July. Prior to break-up, belugas concentrated along this ice-edge and along the adjacent coasts of Bylot Island and eastern Devon Island. There appeared to be considerable movement back and forth along the ice-edge.

Virtually no belugas are present in eastern Lancaster Sound and northwest Baffin Bay from late July until early to mid-September (Johnson et al., 1976b; R.R.C.S., 1977; LGL Ltd., unpubl. data). During this period, belugas are west of the study area in the waters off Somerset Island, southwest Devon Island and the west coast of Brodeur Peninsula, Baffin Island. Sergeant and Brodie (1975) estimated about 10,000 belugas in these waters in early August 1973 and Finley (1976) estimated 8,300 belugas in the offshore waters of Barrow Strait and coastal waters of Somerset Island and southwest Devon Island in late July 1975.

The first belugas recorded during the eastward migration through eastern Lancaster Sound in 1976 were in a herd of 300 animals in Dundas Harbour on 12 September. Surveys on 20 September 1976 indicated that virtually all belugas had left the central arctic areas of Peel Sound and Barrow Strait (Finley and Johnston, 1977). A major migration of belugas through Lancaster Sound occurred from 19-22 September. A total of at least 8,400 animals were counted along the coast of Devon Island during this period (Fig.4-77). Only 320 belugas were observed in the eastern Lancaster Sound study area during the final survey on 26-28 September. Thus, it appears that almost the entire Lancaster Sound population of belugas

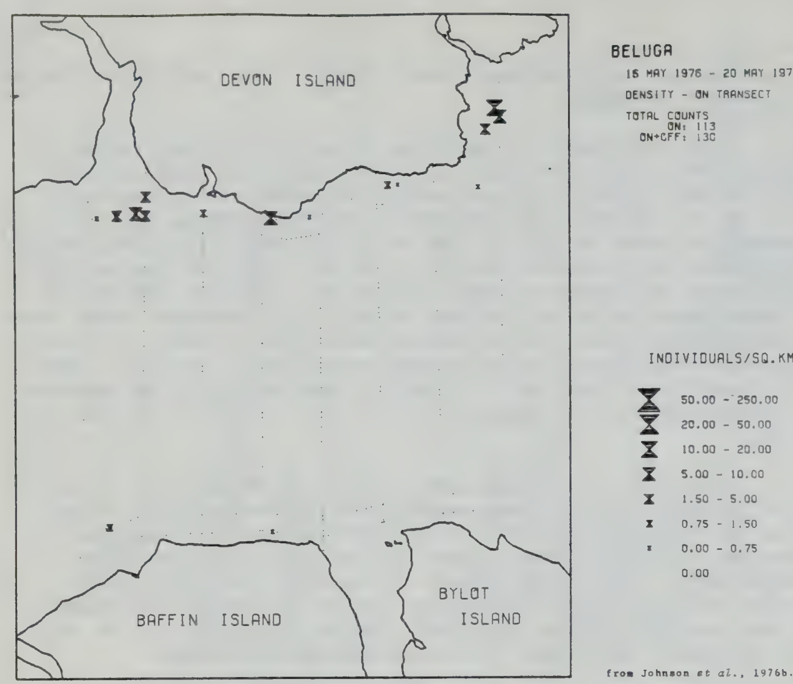


Figure 4-73: Beluga whale counts.

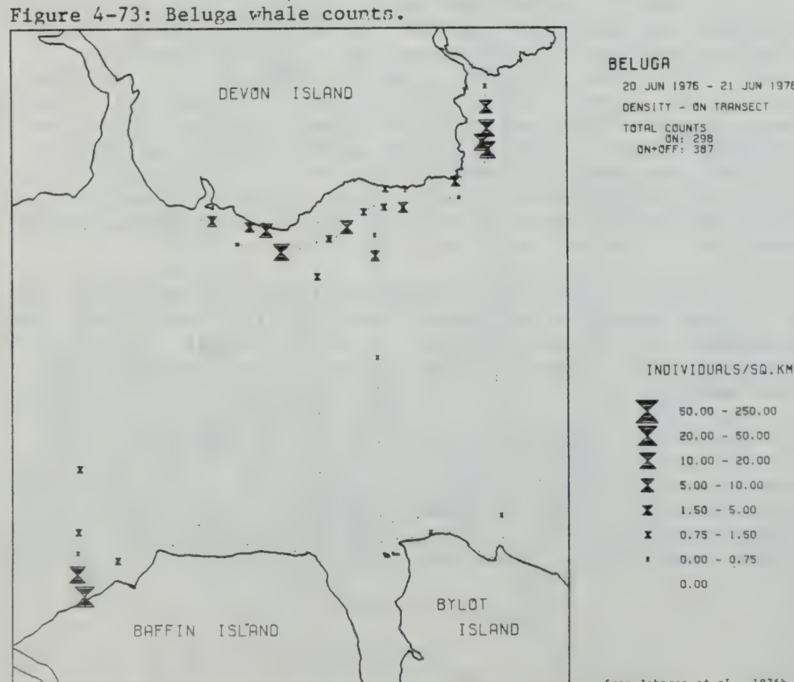


Figure 4-74: Beluga whale counts.

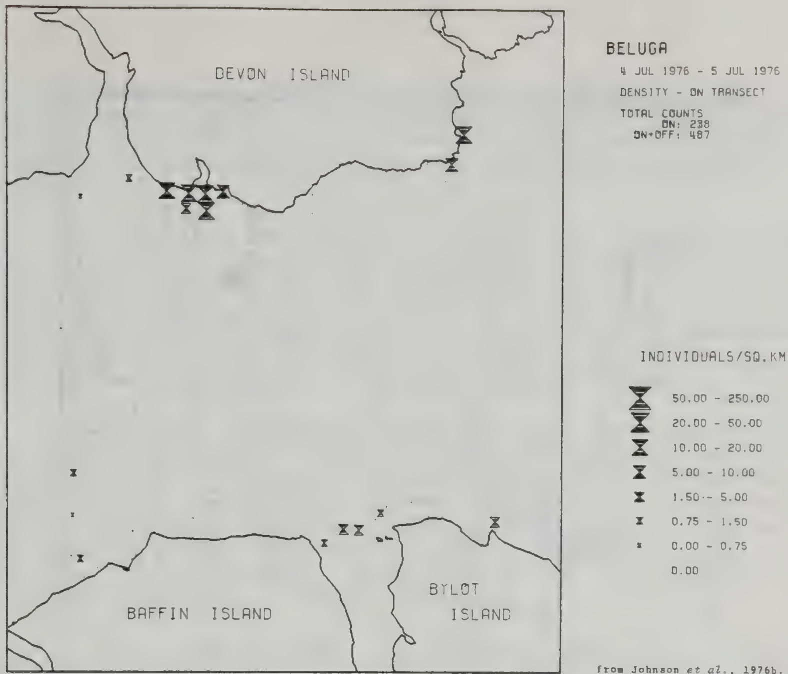


Figure 4-75: Beluga whale counts

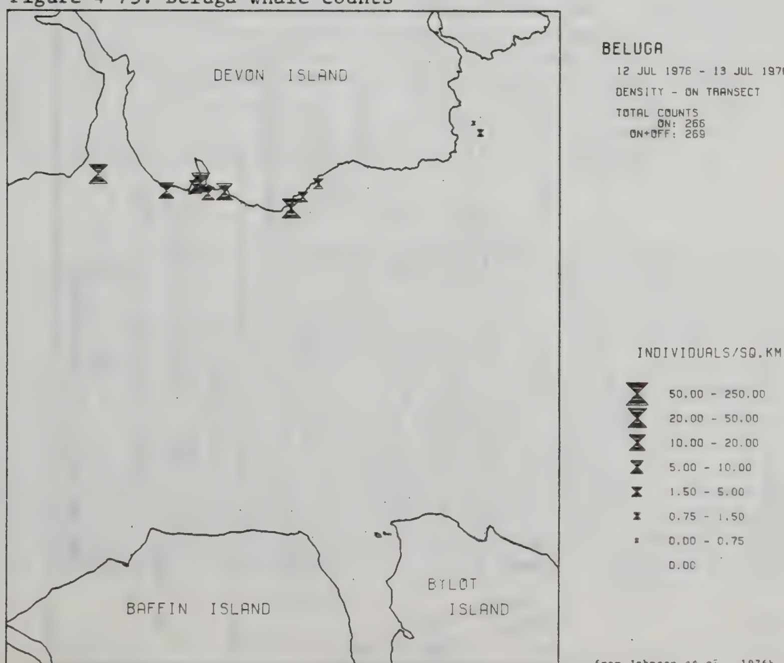


Figure 4-76: Beluga whale counts.

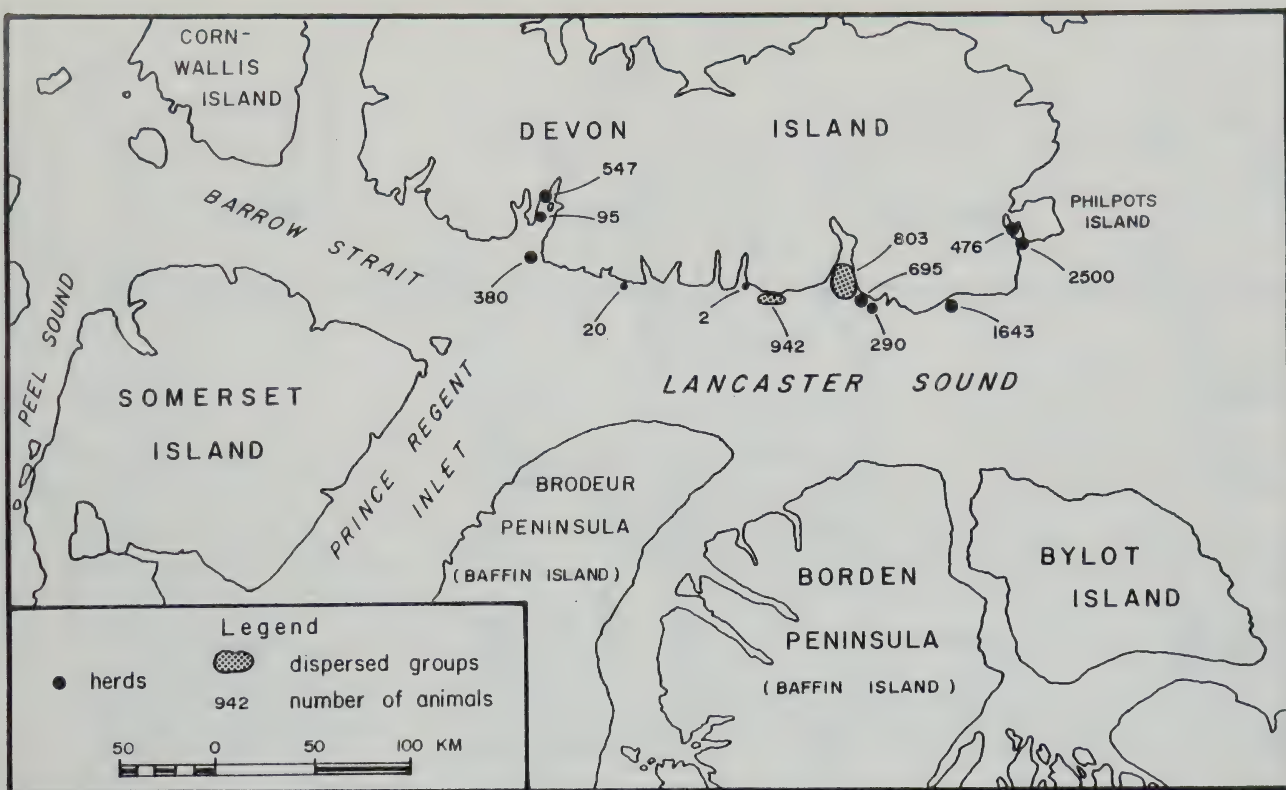


Figure 4-77

Distribution of Belugas During 19-22 September 1976. All observations (8393 animals) probably represent different animals since cases of obvious duplication have been eliminated. (Data from Johnson *et al.*, 1976b; Finley and Johnston 1977, R.R.C.S. 1977.).

migrated through the sound in a period of about one week. This contrasts with the slower and more protracted westward migration in spring and early summer. The autumn migration was conducted exclusively along the south coast of Devon Island.

In 1978 a very similar pattern was observed. Virtually all of the belugas moved eastward through Lancaster Sound during the period 12-15 September. These animals also closely followed the south coast of Devon Island. They then turned north and followed the east coast of Devon Island to Jones Sound and southeast Ellesmere Island. A southward migration through northwest Baffin Bay was not detected.

Belugas are slow growing and slow maturing animals. First breeding appears to be at 5 years for females and 8 years for males. The gestation period is about 14 months and because females nurse their calves for about two years they normally produce a single calf every three years. Extreme ages recorded for belugas are 25-30 years (Brodie, 1969; Sergeant, 1973a); however, direct proof for the validity of the ageing technique is still lacking.

The present status of the Lancaster Sound beluga population is thought to be similar to historical population levels (Sergeant and Brodie, 1975) since it has not been subjected to intensive hunting in recent decades. However, this assumption is unproven since there are no reliable data on historic population levels. Belugas in Lancaster Sound and Baffin Bay were hunted intensively for some years after the decline of the bowhead whale. This commercial harvesting was quite intensive during the late 1800's (cf. Lubbock, 1937) but the effects on population levels are unknown.

4.2.7.2. Narwhal

The narwhal (Monodon monoceros) is found primarily north of 60°N in the Atlantic sector of the northern seas. Its centre of abundance is in the waters of the eastern Canadian Arctic and west Greenland. The winter range of the narwhal has not been fully determined; it winters in the Disko Bay area of west Greenland (Vibe, 1967; Kapel, 1975a) and among the pack ice of southern Baffin Bay and Davis Strait (Lubbock, 1937). The northward migration route is not documented but some animals follow the west Greenland coast north to at least Melville Bay (approx. 76°N); it is not known, however, whether animals destined for northwest Baffin Bay and Lancaster Sound use this route or whether the route is used only by narwhals destined for summering areas in the Thule District of Greenland. In 1978 small numbers of nar-

whal were present in the offshore pack ice between 71°30' and 72°30'N, which suggests that at least some animals destined for Lancaster Sound cross the pack ice at latitudes lower than 76°N. Similarly, the fall migration is not well understood. Some animals follow the west Greenland coast whereas others move south along the border of the southward flowing Baffin Land Current (Vibe, 1967).

Narwhals were present in the offshore pack ice in northern Baffin Bay by early May in 1978. In 1976, the migration into Lancaster Sound began in mid-May. About 2,000 narwhals were estimated to pass through eastern Lancaster Sound from 23 May to 23 June 1976 and approximately three quarters of these animals were in offshore waters over 7 km from landfast ice-edges or ice-free coasts. Davis et al. (1978a) used a complicated series of extrapolations to estimate that at least 20,000 narwhals entered eastern Lancaster Sound during the period of westward migration in 1976. Most of these animals passed through eastern Lancaster Sound during the period 24 June to 15 July; about one half of these animals were in offshore waters (over 7 km from coasts) and the rest were divided equally between the northern and southern margins of the sound.

Two important summering areas are known in the study area: Admiralty Inlet - 8,000 to 10,000 narwhals (B. Kemper, pers. comm.) and the Navy Board Inlet--Eclipse Sound--Pond Inlet complex - 1000+ narwhals (Sergeant and Hay, 1977). Small summering populations may also occur in Coutts Inlet and Buchan Gulf.

In 1976, the eastward migration of narwhals through eastern Lancaster Sound was evidently rapid and occurred in late September. Very few narwhals were recorded on four surveys from 5 to 21 September 1976 (Johnson et al., 1976b; R.R.C.S., 1977). Over 900 were counted, mostly along the coast of Devon Island, on 22-23 September; an additional herd of about 2000 animals was present along the coast of Devon Island, about 25 km west of the study area (R.R.C.S., 1977). Webb (1976) found a herd of 700 narwhals in Eclipse Sound on 22 September 1976. The eastward movement continued on 26-28 September when about 7000 narwhals were estimated to be passing through the study area (Fig.4-78). Surveys were not conducted after 28 September in 1976 so the final stages of the migration were not documented. As was previously mentioned, fall migration routes are poorly understood after the animals leave Lancaster Sound. However, in 1978, about 5000 narwhals were recorded migrating south past Cape Adair on the east coast of Baffin Island during the 29 September - 2 October period.

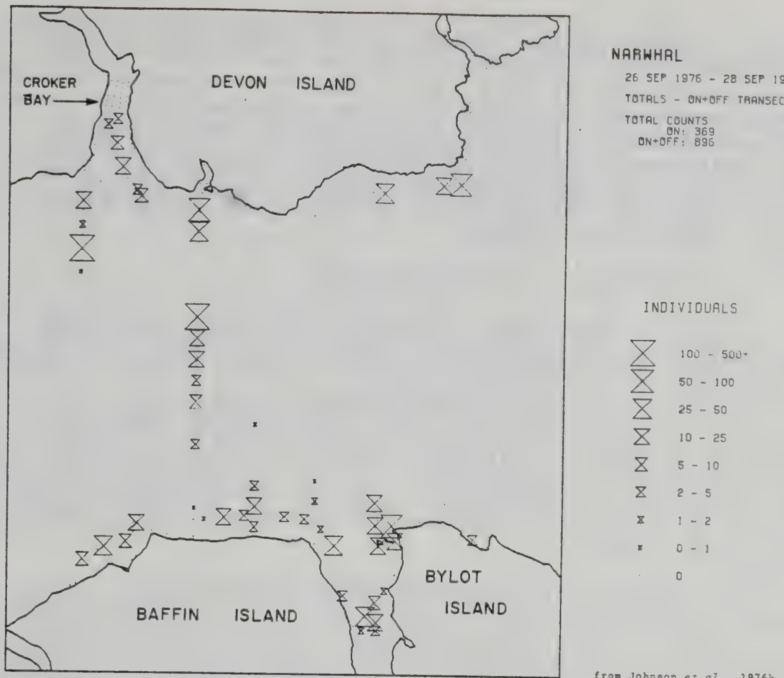


Figure 4-78: Narwhal counts.

The breeding biology of the narwhal is poorly understood, but is thought to be similar to that of the beluga (Mansfield et al., 1975); however, no proven or comparable technique for ageing narwhals has been found (K. Hay, Arctic Biological Station, pers. comm.). There are no reliable estimates of historical population levels of narwhals. The narwhal was commercially exploited in the Lancaster Sound area in the late 1800's when as many as 2800 were taken in a single season (Low, 1906).

4.2.7.3. Bowhead Whale

The Bowhead or Greenland Right Whale (Balaena mysticetus) is a baleen whale (up to 20 m long) that occupies a discontinuous circumpolar range in arctic waters. The populations of bowheads throughout their range were drastically reduced by 19th century whalers. The bowhead has been protected from commercial whaling since the 1930's and is on the U.S. endangered species list. In 1977, the International Whaling Commission attempted to place a moratorium on the killing of bowheads by natives in addition to the commercial ban (Walsh, 1977).

The bowhead was once considered abundant in the eastern Canadian Arctic. Recent estimates of the present status of the population are based largely on guess-work and are conflicting. Mansfield (1971) suggests that bowheads are becoming more numerous whereas Mitchell (1973) states that the population is 'very low' and McVay (1973) calls it 'perilously low'.

Recent sightings of bowheads have mostly been from areas that were former whaling grounds (Mansfield, 1971), indicating that present distribution patterns are similar to historical patterns. Bowheads wintered along the edge of the pack ice in southern Davis Strait, off the mouth of Cumberland Sound, Hudson Strait and along the north coast of Labrador (Brown, 1868; Low, 1906). They appeared along the west coast of Greenland in May in the vicinity of 65^{o} - 70^{o}N (Brown, 1868). Although Brown (1868) stated that they were rarely found south of 65^{o}N, Vibe (1950) cites a reference that bowheads are regularly seen near the ice-edge at 63^{o}N in SW Greenland. During June, bowheads moved north along the coast of Greenland to about latitude $71^{o}30'$N where they crossed by the 'middle ice' to Bylot Island (Brown, 1868). Low (1906) states that the bowheads followed the shore ice north to Melville Bay and then crossed along the southern edge of the 'north water' to NW Baffin Bay. Large numbers concentrated in the fjords of northern Baffin Island and in Prince Regent Inlet during June, July and August (Brown,

1868) and during September and October they began to move south along the east coast of Baffin Island (Brown, 1868; Low, 1906).

In 1978, bowheads were sighted in the offshore pack ice ('the middle ice' of the whalers) in Baffin Bay in May and some had reached the entrance to Lancaster Sound by this time. The main movement into Lancaster Sound occurred in late June and July in 1976 (Johnson _et al._, 1976b; Greendale and Brousseau-Greendale, 1977). Lubbock (1937:393) states that during the last 25 years of commercial whaling, 'large quantities of young whales and their mothers were killed by the whalers in Lancaster Sound and it was this killing ...(that) brought the trade to a standstill'. Evidently Lancaster Sound area was formerly an important nursery area.

Very few bowheads remain in eastern Lancaster Sound during August. Data from both 1976 and 1978 suggest that most bowheads entering eastern Lancaster Sound in June and July move through the area to waters farther west and to the fjords and inlets to the south (Admiralty Inlet and Navy Board Inlet).

The eastward fall migration of bowheads through eastern Lancaster Sound was not detected by the aerial surveys in September, 1976. In 1978, a southward movement along the coast of Bylot Island and past Cape Adair, Baffin Island, was noted in late September and the first half of October; about 50 individuals were recorded.

4.2.7.4. Polar Bears

The polar bear (_Ursus maritimus_) is circumpolar in distribution. In Canada, it is found on sea ice and along arctic seacoasts from the Yukon in the west to Baffin Island in the east and from Ellesmere Island in the north to James Bay in the south. The polar bear is basically a marine species adapted to living on sea ice. It comes to shore during the summer when sea ice is unavailable. Pregnant females occupy terrestrial maternity dens in snow drifts on or near coasts from November to late March or early April (Stirling _et al._, 1977). Denning has been documented on the pack ice of the Beaufort Sea (Lentfer, 1975 cited by Stirling _et al._, 1977) but such denning has not been found in the high Arctic.

Polar bears are present in the study area during the winter, but have not been studied during this period. Apart from females in maternity dens, most bears are on the sea ice at this time. Knowledge of the locations of mater-

nity dens in the area is incomplete (Schweinsburg et al., 1977; Stirling et al., 1977). Known denning areas are found along the east and north coasts of Bylot Island, northeast Brodeur Peninsula, southwest Devon Island, Coutts Inlet and Clyde Inlet. Stirling et al. (1977) suggest that suitable habitat for maternity denning appears 'superficially at least, to be virtually unlimited' in the Canadian archipelago. Thus, dens are widespread in low densities along coasts.

The distribution of polar bears and the relationships of bears to different ice types have not been systematically quantified in the northwest Baffin Bay - Lancaster Sound area. By mid-April all bears are on sea ice where they hunt their main prey - the ringed seal. Studies in 1976 and 1978 suggest that bears are widespread on suitable ice (including offshore pack ice). However, in summer, polar bears are known to concentrate in large inlets and fjords where ice remains until late July or early August. Concentrations are known to occur in Radstock Bay and Maxwell Bay on southwest Devon Island (Stirling, 1974; Stirling et al., 1977), and probably occur in Croker Bay, Bethune Inlet and Navy Board Inlet after the ice has cleared from eastern Lancaster Sound.

Polar bears move to land after the ice has disappeared from Lancaster Sound and associated fjords. These summer retreats are occupied until new ice forms in the fall. Schweinsburg et al. (1977) suggest that most of the coasts of the eastern Lancaster Sound area are used as summer retreats but no areas with large concentrations are known. Schweinsburg et al. (1977) found that females with cubs and young bears of both sexes used the coastal summer retreats. Adult males tended to be more wide-ranging with some moving inland and others remaining on floating pan ice. Polar bears can rarely catch seals during the open water season and thus, they probably feed lightly during their occupancy of summer retreats. Polar bears are still widespread in low numbers on the offshore pack ice in northwest Baffin Bay in August and September. There is no information about the distribution of bears in the fall when they occupy newly forming ice.

4.2.7.5. Walrus

The walrus (*Odobenus rosmarus*) occupies a discontinuous circumpolar range which at present is restricted to waters north of 60°N. The largest Canadian populations occur in Foxe Basin and northern Hudson Bay. The numbers and movements of walruses in the eastern high Arctic are not well understood.

Small numbers of walrus overwinter in several areas with permanent open water in the central high Arctic (Finley, 1976; Davis et al., 1978b; Kiliaan and Stirling, 1978). Walruses are also known to overwinter in the Thule District of west Greenland (Freuchen and Salomonsen, 1958), and are also found on the Canadian side of the 'North Water'. The known wintering areas are used by only a portion of the summering population. The wintering area of the migrants is unknown.

Small numbers of walruses were present at the entrances to Jones and Lancaster Sounds in April and May, 1978.

The peak of the terrestrial haul-out period occurs during the first three weeks of August, although some sites are occupied both earlier and later. By this time the size of the walrus population that actually summers in eastern Lancaster Sound is small (only 100-150--Norlands Ltd., 1978). Several hundred walruses migrate through eastern Lancaster Sound to haul-out sites in the central Arctic (Davis et al., 1978b).

Several haul-out sites are known and others are suspected in Jones Sound. These areas have not been systematically censused and the size of the Jones Sound population is unknown. These animals migrate through and some may winter in northwest Baffin Bay.

The present status of the population of walruses that uses northwest Baffin Bay is not well known. If, as suggested by Freuchen (1921) and Freuchen and Salomonsen (1958), the walruses move south into Davis Strait and cross to the west coast of Greenland, then this population may have been subjected to hunting in these areas. Walruses were heavily exploited in Davis Strait and the populations were much reduced (see Davis et al., 1978c for a review). It is now known to what extent recovery has occurred.

4.2.7.6. Harp Seal

The harp seal (Phoca groenlandica) occurs in three isolated breeding populations in the North Atlantic. The largest population breed and pups in March on pack ice off southern Labrador and Newfoundland and in the Gulf of St. Lawrence. A large proportion of this population migrates north into the waters of Davis Strait, Baffin Bay, Lancaster Sound and Jones sound during the summer (Sergeant, 1965).

Harp seals begin their northward migration in late April and May, after the breeding and moulting period. They

follow the coast of Labrador and southern Baffin Island until their migration is deflected by pack ice away from Baffin Island towards the coast of west Greenland (Mansfield, 1967). The harp seals reach southwest Greenland by mid-June; most apparently continue north along the ice-free Greenland coast with an undetermined proportion reaching Thule district (Sergeant, 1965; Kapel, 1975b). The migration routes of harp seals that enter Lancaster Sound and Jones Sound in July and August are unknown. During the northward migration, adult harp seals precede the younger animals and comprise the majority of those animals that penetrate into Lancaster Sound (Sergeant, 1965; Greendale and Brousseau-Greendale, 1977).

In 1976, the westward migration of harp seals into Lancaster Sound began in early July and continued throughout the month (Greendale and Brousseau-Greendale, 1977). A total of nearly 16,000 harp seals were counted passing Cape Hay, Bylot Island, in July. Weekly aerial surveys indicated that most harp seals entered eastern Lancaster Sound along its southern margin during the first three weeks of July. However, during the last week of July, harp seals also entered along the south coast of Devon Island (Johnson et al., 1976b). There is very little information about the numbers entering Jones Sound.

The influx of harp seals was finished by the end of July; few seals were recorded in northwest Baffin Bay or eastern Lancaster Sound during August. Most harp seals evidently move through Lancaster Sound into the central Arctic and into Admiralty and Navy Board Inlets. Others are probably in Jones Sound.

The eastward migration of harp seals through eastern Lancaster Sound began in early September 1976 and movements occurred throughout the month. Most individuals were recorded in coastal waters within about 2 km from shore and movements proceeded along both the northern and southern margins of Lancaster Sound. Migration routes through northwest Baffin Bay are poorly understood at present.

The present status of the harp seal in northern Baffin Bay and Lancaster Sound is unclear. Harp seals are commercially exploited on their pupping grounds and the population size of the west Atlantic herd has decreased from about 3,000,000 in 1951 (Mansfield, 1967) to about 1,200,000 animals (excluding pups) at present (Lett and Bejaminsen, 1977). Tuck (1957) observed about 150,000 harp seals migrating west past Cape Hay, Bylot Island, in July 1957. However, Greendale and Brousseau-Greendale (1977) repeated these observations in late June and July 1976 and counted only

16,000 harp seals moving west in Lancaster Sound. The differences in numbers of harp seals present in Lancaster Sound in 1957 and 1976 are undoubtedly real and are not due to sampling artefacts. The significance of the observed nine-fold decline in numbers is entirely unknown. The decrease may be a result of the general decrease in harp seal numbers or there may be large annual variations in the numbers of harp seals that reach the waters of Lancaster Sound. These variations could be related to ice conditions and/or food availability along the east Baffin or west Greenland coasts.

4.2.7.7. Ringed Seal

The ringed seal (*Phoca hispida*) is the most abundant and widespread marine mammal in the Canadian Arctic (Mansfield, 1967). The wide distribution of the ringed seal is attributed to its ability to maintain breathing holes in the sea ice - a unique adaptation that allows it to exploit food resources in an otherwise inaccessible environment. The sea ice is critical to the breeding success of ringed seals as it provides a platform on which they pup and nurse their young. The young ringed seals are born in birth lairs hollowed out of snow drifts on the fast ice (Smith and Stirling, 1975); the young are nursed for about six weeks (McLaren, 1958). The stability of the ice platform during the period of pupping (April) is critical to breeding success and since the most stable ice is found in complex coastal areas, the highest concentrations of ringed seals are found in such areas (McLaren, 1958; Smith, 1973).

Adult ringed seals are fairly evenly dispersed within areas of suitable fast ice (Finley, 1976). Immature, non-breeding seals, on the other hand, tend to occur offshore among unstable ice in winter (Smith, 1973) and along active fracture zones between landfast ice and offshore ice (K. Finley, LGL Ltd., pers. comm.). At least some non-breeding seals move from offshore areas into areas with fast ice during the period of spring haul-out in June (McLaren, 1958; Finley, 1976).

Ringed seals begin to haul-out onto the fast ice in late May and this behaviour continues through June and July when ice conditions permit. The spring haul-out of seals corresponds to the period of moult; haul-out behaviour and the moult are thought to be functionally related (McLaren, 1958a; Smith 1973).

Comprehensive surveys of ringed seals were not conducted in Lancaster Sound in 1976, since areas of landfast ice were not surveyed adequately. The results of Johnson *et*

al. (1976b) indicate that ringed seals were fairly evenly distributed in low densities throughout areas of offshore pan ice in eastern Lancaster Sound in June. Preliminary results from 1978 surveys suggest that large numbers of ringed seals occupied the offshore pack ice in northwest Baffin Bay in May, June and early July. There is no information on the ages or reproductive status of these animals. Surveys of landfast ice in 1978 have not yet been analyzed.

Ringed seals cannot be censused reliably from the air during the open water season, hence, little can be said about their distribution in the study area during this period. Stirling et al. (1977) indicated that long distance movements of young seals occur in the western Arctic in late summer and fall; however, the frequency of such movements is unknown, and no similar evidence is available for the eastern Arctic.

The ringed seal is an important component of the economy of all coastal Inuit settlements. Bissett (1967) estimated an annual harvest of 3000 to 4500 ringed seals at Pond Inlet and 2000 to 3000 at Arctic Bay in the mid-1960's. Treude (1977) estimated that about 2500 ringed seals were taken by Pond Inlet residence in 1972-73.

4.2.7.8. Bearded Seal

The bearded seal (*Erignathus barbatus*) is sparsely distributed throughout its circumpolar range (Burns, 1967). It is found in virtually all coastal marine waters in arctic Canada (Mansfield, 1967). The bearded seal is known to maintain breathing holes in fast ice but this practice is uncommon and most bearded seals withdraw from areas where fast ice forms during winter or overwinter in areas where currents maintain thin ice or polynias (Burns, 1967; Finley, 1976). Bearded seals depend on shallow, coastal areas with high benthic productivity (Mansfield, 1967) during the open water season.

Bearded seals are widespread but relatively uncommon in the northwest Baffin Bay - Lancaster Sound study area. During the spring period of 1978 they were widespread throughout areas of unstable ice and substantial numbers were found on the offshore pack ice of northwest Baffin Bay. Results from 1976 suggest that several hundred bearded seals migrated through Lancaster Sound during May, June and July but that few (less than 100) actually summered there (Norlands Ltd., 1978).

In the open water season bearded seals were found primarily in coastal waters. Summer concentrations were noted in 1978 at the glacier fronts along the south coast of Ellesmere Island and the east coast of Devon Island (e.g., Benthune Inlet). Bearded seals were also common in parts of Navy Board Inlet. The fall migration out of the study area was prolonged and occurred gradually.

4.2.7.9. Other Species

Killer Whale (*Orcinus orca*). Small numbers of killer whales are reported by the Inuit to enter Pond Inlet and Eclipse Sound during the open water season in late July and August (Degerbol and Freuchen, 1935; Miller, 1955; Bissett, 1967). Miller (1955) stated that 10 to 209 killer whales were involved in this movement. A few killer whales were occasionally noted at Dundas Harbour in the 1940's (Duvall and Handley, 1946; Gunn, 1949; Lawrie, 1950). No killer whales were recorded in eastern Lancaster Sound during the surveys in 1976 but two were observed in October 1975 (Johnson *et al*., 1976b; R.R.C.S., 1977). In 1978, 11 to 13 were recorded in the study area.

Hooded Seal (*Cystophora cristata*). Hooded seals whelp their pups on ice floes off Newfoundland and in Davis Strait (Sergeant, 1976a). A proportion of the population moves north into Baffin Bay in the summer and some evidently reach Lancaster Sound (Mansfield, 1967). Bissett (1967) notes that hooded seals are rarely taken by the hunters of Pond Inlet. Hooded seals occasionally penetrate into Lancaster Sound. A single animal was found killed by a polar bear in Radstock Bay (Stirling and Archibald, 1977). Greendale and Brousseau-Greendale (1977) recorded only one hooded seal during their observations from Cape Hay. Four individuals were seen during aerial surveys in 1976 (Johnson *et al*., 1976b) and 16 individuals were recorded during aerial surveys in 1978.

Harbour Seal (*Phoca vitulina*). The harbour seal occurs in coastal areas throughout much of Canada (Mansifeld, 1967). Its status along the coast of Baffin Island is not well known; it has been taken at Arctic Bay and Pond Inlet (Mansfield, 1967). Bissett (1967) states that the harbour seal is known in the Pond Inlet area, but not in large numbers. No harbour seals were recorded during the aerial survey in 1976 or during the migration watches from Cape Hay (Greendale and Brousseau-Greendale, 1977; Johnson *et al*., 1976b; R.R.C.S., 1977). No harbour seals were recorded in 1978.

Arctic Fox (Alopex lagopus). Arctic foxes have long been known to move onto sea ice during winter where they scavenge at the remains of seals killed by polar bears (Freuchen and Salomonsen, 1958). It has recently been discovered that foxes are important predators of ringed seal pups in the western Arctic (Smith, 1976). No studies of the use of sea ice by arctic foxes in the study area have been conducted.

4.2.8 Habitat Use by Birds

The seasonal distributions, numbers and movements of birds in northwest Baffin Bay and eastern Lancaster Sound were outlined in subsections 4.2.6. Here we discuss the relative importance of various general habitat types to birds and summarize the information presented in the previous sections so that the reader can evaluate the densities and proportions of various populations that use particular habitats during different seasons.

The only available quantitative information about habitat use by sea-associated birds in the northwest Baffin Bay area is that obtained in eastern Lancaster Sound in 1976 for Norlands Petroleums Ltd. Comparable data for a much broader part of NW Baffin Bay will be available after results of the 1978 Petro-Canada surveys are anlayzed. Because of year-to-year differences in ice conditions and the restricted area studied in 1976, results from the 1976 studies will not be fully representative of the situation in NW Baffin Bay in 1978 or other years. However, many of the major findings in 1976 should apply to the present area of interest. Pending analysis of 1978 data, the main results of 1976 studies are summarized below.

During aerial surveys in eastern Lancaster Sound in 1976, birds were classified as using waters within 400 m of landfast ice-edges; waters within 400 m of ice-free coasts; waters from 400 to 1400 m from ice-free coasts and landfast ice-edges; and offshore waters over 1.4 km from ice-free coasts and landfast ice-edges (Johnson et al., 1976a). Within these general habitats more specific associations of birds with pack ice, water depth, glacier fronts and so on were noted.

4.2.8.1. Spring

Figure 4-79 summarizes, for each major bird species, the average number of birds seen per 5 km of aerial transect in each habitat during the 2 May to 7 June 1976 period. Also presented, on the right side of the figure, are

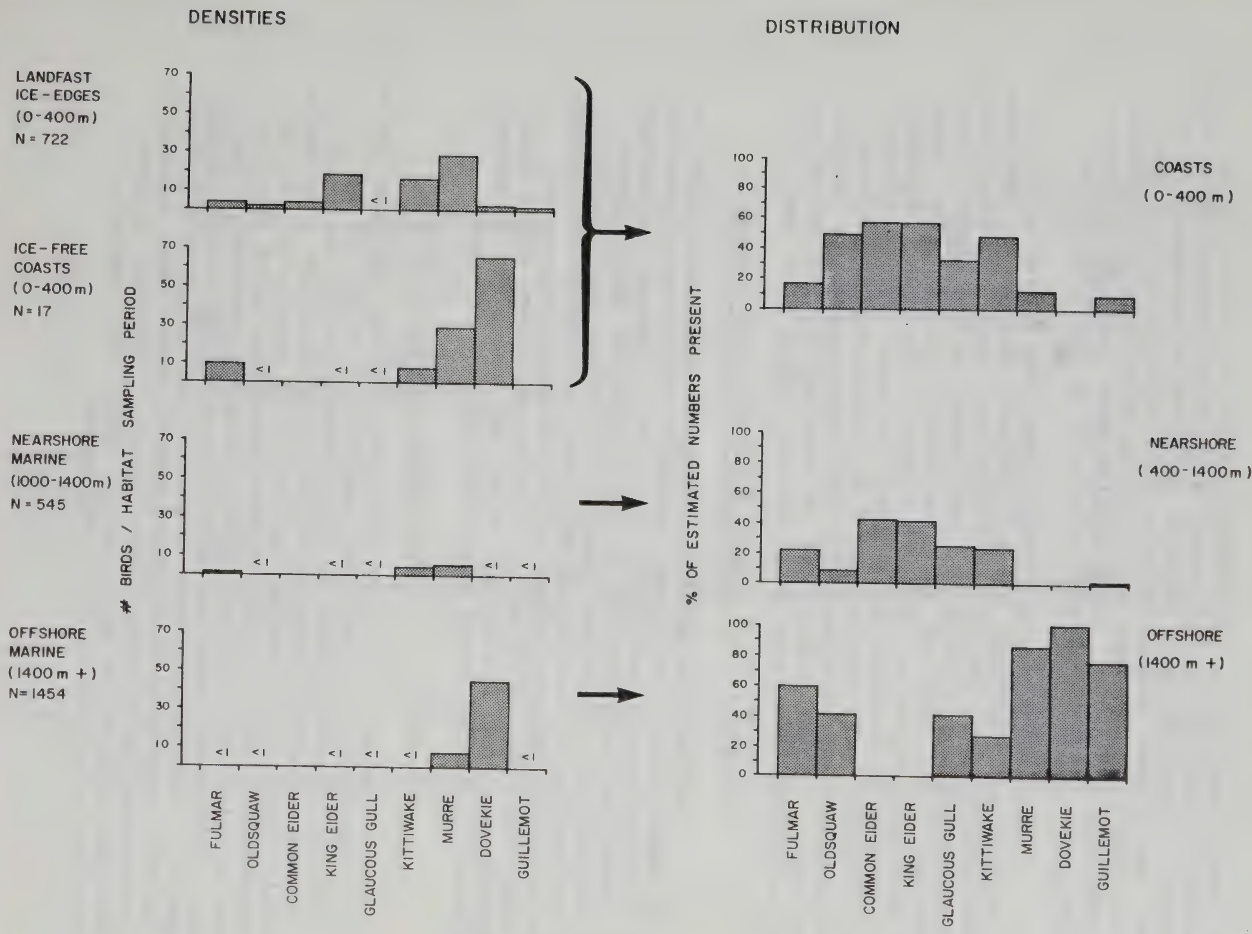


Figure 4-79.

Densities (nos./5 km of transect) in Various Habitats and Distribution of Seabirds in Eastern Lancaster Sound, 2 May - 7 June, 1976. See text for details. Data from Johnson *et al.* (1976a).

the proportions of the estimated numbers of each major species in the study area (eastern Lancaster Sound) that were present in each of three general habitats on selected dates. Thus, the highest densities of several species were found along landfast ice-edges and ice-free coasts but significant proportions of many of these species were found in the much larger area of offshore waters, albeit at lower densities.

Most Oldsquaw and Common and King Eiders occurred in coastal and nearshore waters, probably due to the requirements of these species for shallow-water feeding areas. Most murres (excluding those on or very close to the colony near Cape Hay) and almost all Dovekies within the Lancaster Sound study area occurred in offshore waters. The latter species was seen in cracks and leads among the pack-ice in 1978 as well as 1976. In offshore habitats, murre densities were similar in areas with small versus large percentages of pan-ice cover. In offshore areas, fulmars and guillemots occurred in highest densities in areas with dense pack ice.

4.2.8.2. Late Spring and Early Summer

During this period, surveys of Lancaster Sound in 1976 showed that coastal and nearshore waters were important to most sea-associated birds (Fig.4-80). Except for murres and Dovekies, densities of all major species were highest along ice-free coasts and landfast ice-edges and a majority of the estimated numbers of such species occurred in coastal and nearshore waters. Most of the estimated numbers of murres and Dovekies occurred in offshore waters where both species preferred areas with 5-25% pan ice-cover; Dovekies apparently avoided areas with less than 5% ice-cover.

4.2.8.3. Late Summer and Early Fall

Eastern Lancaster Sound was largely ice-free during this period of 1976, but small amounts of drift ice and occasional icebergs were usually present in the study area. Oldsquaws, eiders, Glaucous Gulls, kittiwakes and guillemots mainly occurred in coastal and nearshore waters and all of these species occurred in highest densities along ice-free coasts (Fig. 4-81). Most of the estimated numbers of fulmars, murres and Dovekies present occurred in offshore waters. In offshore areas, fulmars occurred in high densities with pan ice, around icebergs and along long, narrow convergences of offshore water masses. Dovekies avoided ice-free offshore waters; too few murres were detected offshore to determine habitat preferences.

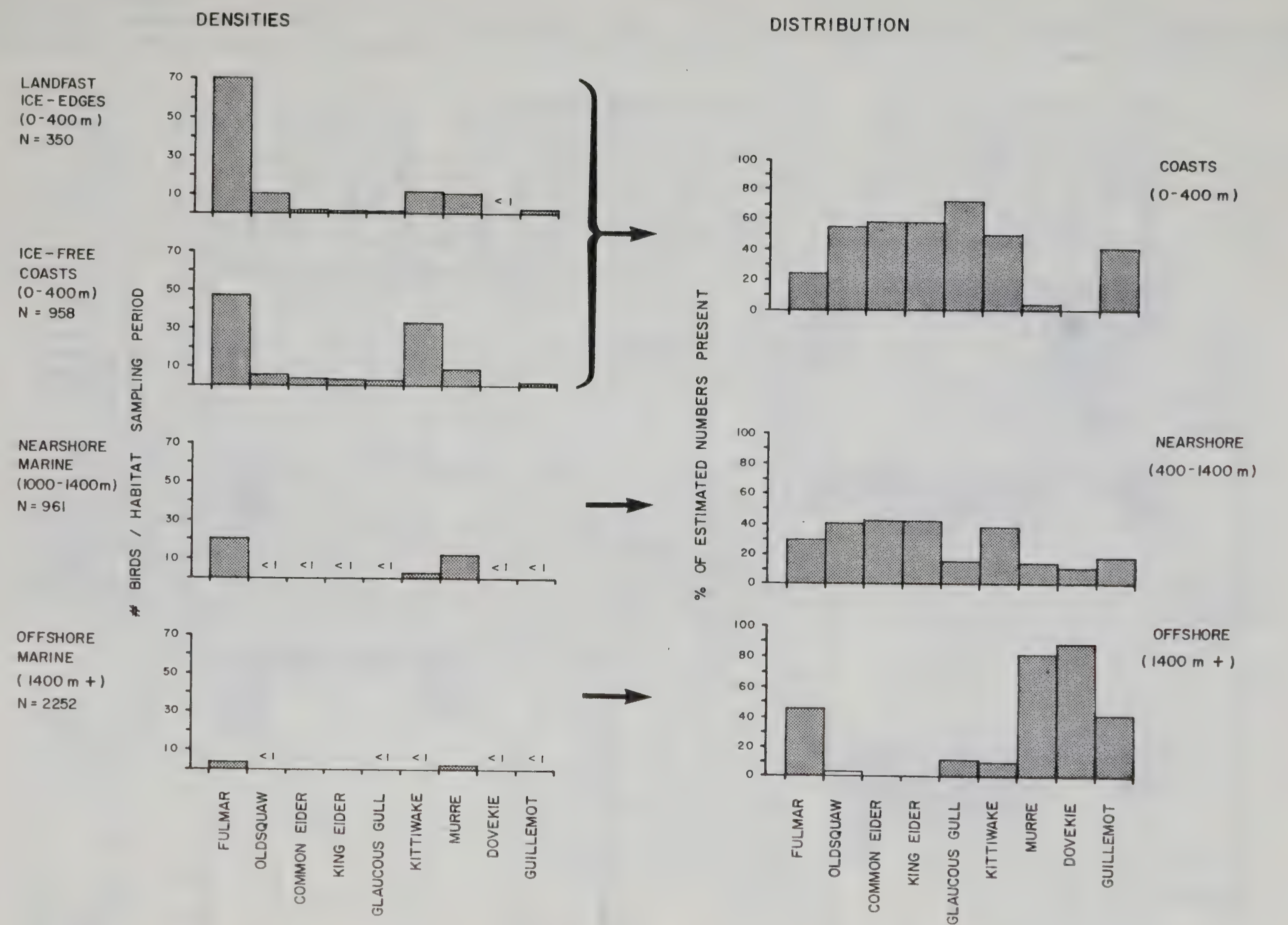


Figure 4-80.

Densities (nos./5 km of transect) in Various Habitats and Distribution of Seabirds in Eastern Lancaster Sound, 13 June - 10 August, 1976. See text for details. Data are from Johnson *et al.* (1976a).

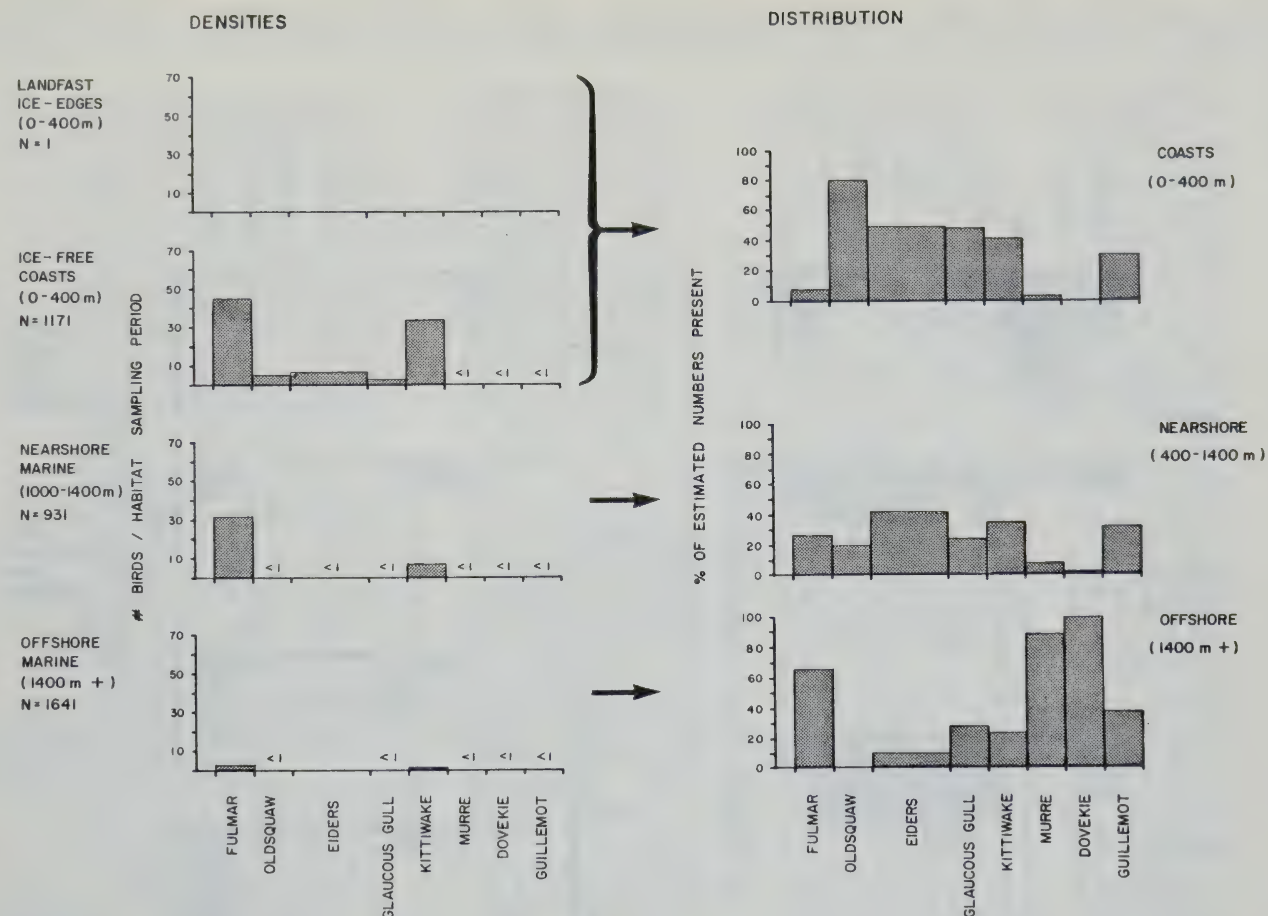


Figure 4-81

Densities (nos./5 km of transect) in Various Habitats and Distribution of Seabirds in Eastern Lancaster Sound, 16 August - 28 September, 1976. See text for details. Data are from Johnson *et al.* (1976a).

4.2.9 Trophic Relationships in High Arctic Marine Systems

It has been shown that northwest Baffin Bay and Lancaster Sound support large numbers of seabirds and marine mammals. Pending analysis of data collected by Petro-Canada in 1978, almost no information exists on marine fish or benthic invertebrates in the area. However, some lower elements of the food chain (phytoplankton and zooplankton) leading to birds and mammals are present in abundance. Only one dietary study, that of Bradstreet (1976) dealing with five species of seabirds, had been conducted in NW Baffin Bay or Lancaster Sound up to 1978. Results of 1978 studies of seabird and marine mammal diets are not yet available. The general results of other arctic studies have been used below to suggest important trophic relationships.

Relationships among Canadian arctic marine mammals and their food are, in general, poorly understood. Quantitative information exists on the diets of some of the seabird species in or near Lancaster Sound, but none exists for any marine mammal. Very little is known about the food preferences of arctic fish and marine invertebrates, although recent studies by Moore and Moore (1974), Bohn and McElroy (1976), Buchanan et al. (1977), Bain and Sekerak (1978), Craig and Griffiths (1978), and Frost et al. (1978) have begun to elucidate some of these relationships. Most existing information is qualitative (lists of species eaten) and yields little or no insight into the relative importance of various food species. In addition food requirements change, depending upon season and activities (e.g., egg-laying, rearing young, moulting, growth, etc.). Food availability and preference also influence individual diets.

Additional factors complicating interpretation of the few trophic studies undertaken in the Arctic are variable and often inadequate methods of expression of results, and lack of information about the actual food value of the food organisms. Many studies have reported only the species or, more often, major groups eaten (e.g., fish, copepods, amphipods). Other studies report numbers of each species eaten, but not weight; when it is reported, weight can be reported as wet weight or dry weight. Although dry weight best approximates energy content of the diet, the actual caloric values of food species are seldom known.

For the following discussion food taxa have been assigned to major groups on the basis of knowledge of their distribution and habitat preferences:

1. Zooplankton--these animals occur planktonically in the upper water layers.

2. Arctic cod--demersal, pelagic or ice-associated. Given the importance of arctic cod to various seabirds and marine mammals, this species is considered separately from other fish.

3. Ice-associated amphipods--closely associated with ice when present; when ice melts, may occur in the plankton, benthos, or both.

4. Nearshore animals--includes crustaceans, molluscs, sculpins primarily found benthonically in shallow coastal waters.

5. Other animals--polychaetes, other annelids, larval barnacles, squid and rarely-detected amphipods (e.g., _Eusiris_, _Weyprechtia_, _Syrrhoe_, _Paroediceros_, _Ischyrocerus_, etc.).

4.2.9.1 Seabirds

The feeding habits of five species of seabirds in Lancaster Sound and east Barrow Strait were studied by Bradstreet (1976, 1977), mainly by analysis of stomach contents. These studies present information on diets during different activities of seabirds as well as data on diets in different feeding habitats. For each bird species and situation, the relative importances of various food taxa were assumed to be the estimated dry weights of the various food organisms _at the time of ingestion_ as percentages of the total food ingested. Two important assumptions were that

1. the presence of fish otoliths indicated recent ingestion of whole fish (Uspenski, 1958; Sanford and Harris, 1967; C. Swennen, Netherlands Inst. for Sea Research, pers. comm.), and

2. the presence of squid (_Gonatus_ spp.) beaks did not indicate recent ingestion of squid since these horny plates remain for long periods in seabird stomachs (Clarke, 1962).

4.2.9.1.1 Pre-hatching Period

Figure 4-82 shows the major trophic relationships of some seabird species occurring along nearshore and offshore edges of fast ice in East Barrow Strait during the

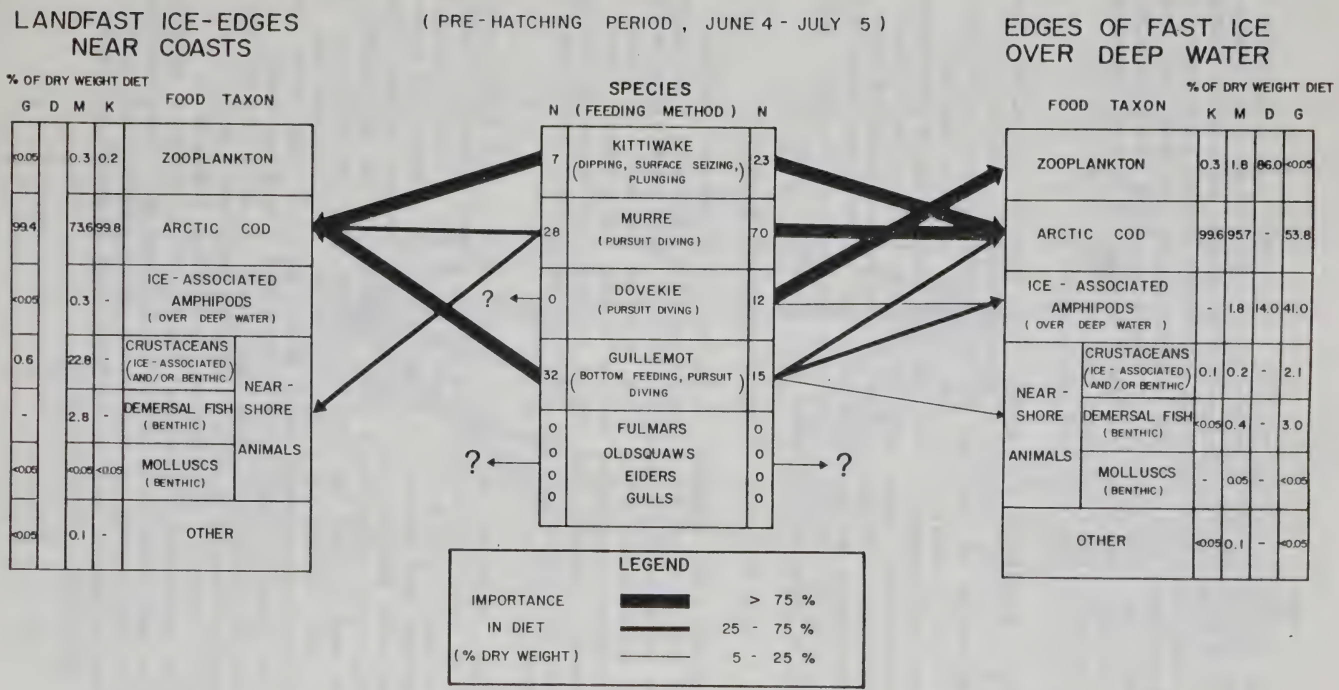


Figure 4-82

Food-web Relationships of Some Arctic Seabirds During the Period Prior to the Hatching of the Young (adapted from Bradstreet, 1977).

early portion of the nesting cycle. (No data are available for Lancaster Sound or NW Baffin Bay at this time). Although several seabird species concentrated in these habitats, these birds also occur in the extensive offshore areas far from coasts and ice-edges during the pre-hatching period; nothing is known about the food habits of these species when pelagically distributed. Data on the food habits of other abundant species (fulmars, gulls) in East Barrow Strait during the pre-hatching period are not yet published.

Along landfast ice-edges near coasts and along the edges of fast ice over deeper offshore waters, arctic cod formed the majority of the dry weight in the diets of kittiwakes (100% near coasts, 100% over deeper water), murres (74%, 96%) and guillemots (99%, 54%). Along coasts nearshore animals were somewhat important to murres (25%), and along offshore ice-edges, ice-associated crustaceans were of considerable importance to guillemots (41%). Dovekies were collected only along offshore ice-edges, where zooplankton (primarily calanoid copepods) formed 86% of their diet.

4.2.9.1.2 Chick-rearing Period

During late summer, fulmars, kittiwakes, murres, dovekies and guillemots were collected in offshore and nearshore marine waters of Lancaster Sound. Some individuals of each species were associated with pan-ice in each of these two major habitat categories while others were taken from ice-free waters. Arctic cod again formed the majority of the dry weight in the diets of all species collected in either habitat (Figure 4-83), except Dovekies.

Three species, the kittiwake, murre and guillemot, relied on fish (mainly arctic cod) to a great extent (87-97% of energy intake-Table 4-12). About half of the individuals of these species had recently consumed fish. When all stomach samples were pooled, the numbers and energy intake from invertebrates were relatively low. Dovekies, in contrast, ate few fish and relied on invertebrates for the majority of their food. Two groups of invertebrates, zooplankton and ice-associated crustaceans, were about equally important to Dovekies. Northern Fulmars ate about 800 times as many invertebrates as fish, and fish occurred in only 29% of the fulmar stomachs examined, but fish represented 63% of the pooled energy intake. In view of the large numbers of invertebrates consumed, it seems likely that fulmars select invertebrates and take fish opportunistically. Zooplankton were somewhat important in the diets of fulmars taken both in nearshore and offshore marine waters (26% and 30% of total dry weight consumed, respectively).

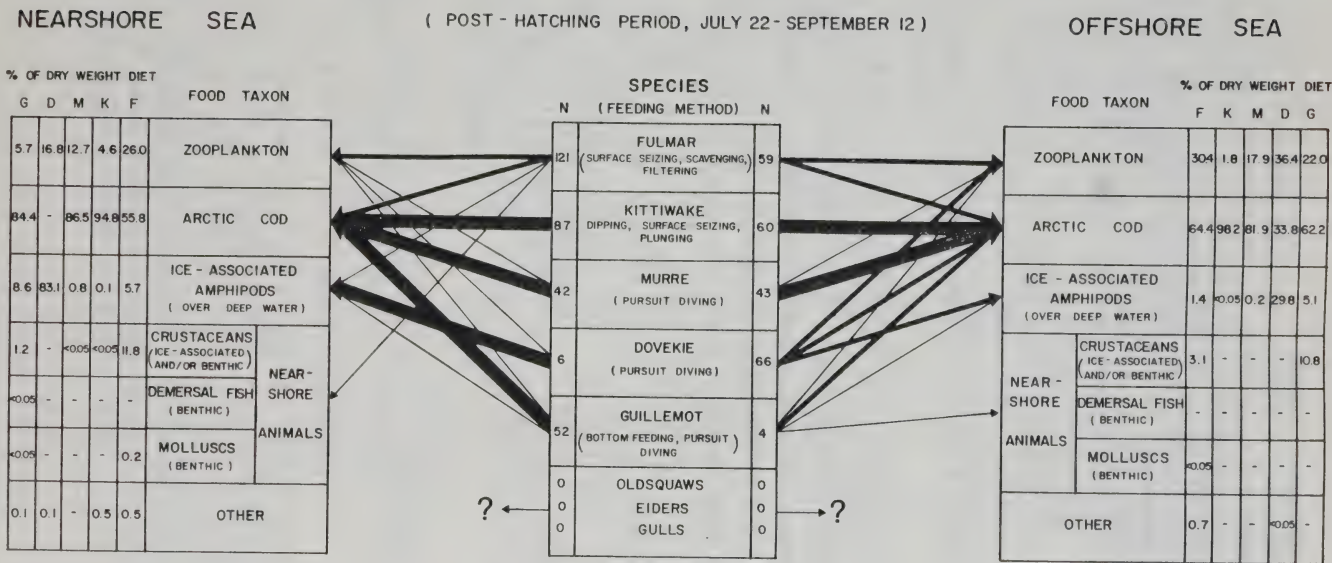


Figure 4-83

Food-web Relationships of Some Arctic Seabirds During the Chick-rearing Period (adapted from Bradstreet, 1976). Legend as in preceding Figure.

Table 4-12:
Aspects of the Importance of Cod to Various Seabirds During the Chick-rearing period.[1]

	% of Individuals Taking Arctic Cod	% of Energy Intake Comprised of Arctic Cod[2]	Ratio of # Invertebrates to # Fish Found in Stomachs[3]
Northern Fulmar	29	63	800
Black-legged Kittiwake	43	97	142
Thick-billed Murre	60	88	44
Dovekie	9	35	388
Black Guillemot	50	87	30

[1] Birds from nearshore sea and offshore habitats combined.

[2] For calculations, see Bradstreet (1976).

[3] Based on all stomachs examined.

4.2.9.1.3 Other Seabirds

No information is available on the feeding habits of Oldsquaw or eider ducks in or near Lancaster Sound. Alliston et al. (1976) reported that the amphipods Parathemisto libellula and Gammarus setosus were probably the two most important food taxa in the diet of 14 Oldsquaws collected nearshore in Creswell Bay, Somerset Island, during August. Johnson (1978) determined that Oldsquaws collected in the nearshore Beaufort Sea during summer contained, on an observed wet-weight basis, 55% mysids, 19% amphipods, 8% bivalve molluscs, 2% isopods, 2% small fish and 16% unidentified material. These birds were apparently feeding at or near the bottom. In arctic Russia, the Common Eider eats primarily the bivalve mollusc Mytilus edulis (84% total amount of food--Belopol'skii 1957).

Other than kittiwakes, no larids have been collected for studies of food habits in eastern Lancaster Sound. In Russia, Belopol'skii (1957) found that Glaucous Gulls had a diverse diet, eating fish, molluscs, crustaceans, echinoderms, birds, mammals, berries and offal. Johnson (1978) concluded that Glaucous Gulls feed opportunistically in the nearshore Beaufort Sea where the diet is also diverse: isopods (33% of observed wet weight), amphipods (23%), birds (18%), small fish (12%) and euphausiids, bivalves, tunicates, hydroids and unidentified material (14%). Alliston et al. (1976) report that five Thayer's Gulls collected in nearshore waters of Creswell Bay, Somerset Island, contained 99% Parathemisto libellula (amphipod). At the time of collection, vast numbers of P. libellula were stranded on the tideflats where the gulls were collected. In the Chukchi Sea and at Point Barrow, Alaska, Ivory Gulls apparently feed primarily on arctic cod (Divoky, 1976) and less so on amphipods and other crustaceans.

Based on the information cited above, suspected trophic relationships for species of seabirds not collected in eastern Lancaster Sound are presented in Figure 4-84.

4.2.9.2 Marine Mammals

No quantitative studies of the diets of marine mammals in or near northwest Baffin Bay had been undertaken before 1978, and 1978 data are not yet available. The following accounts are based on information from other arctic areas. The available information is generally qualitative and the accounts are, consequently, sometimes speculative in nature. A more detailed review of marine mammal diets in the arctic appears in Davis et al. (1978c).

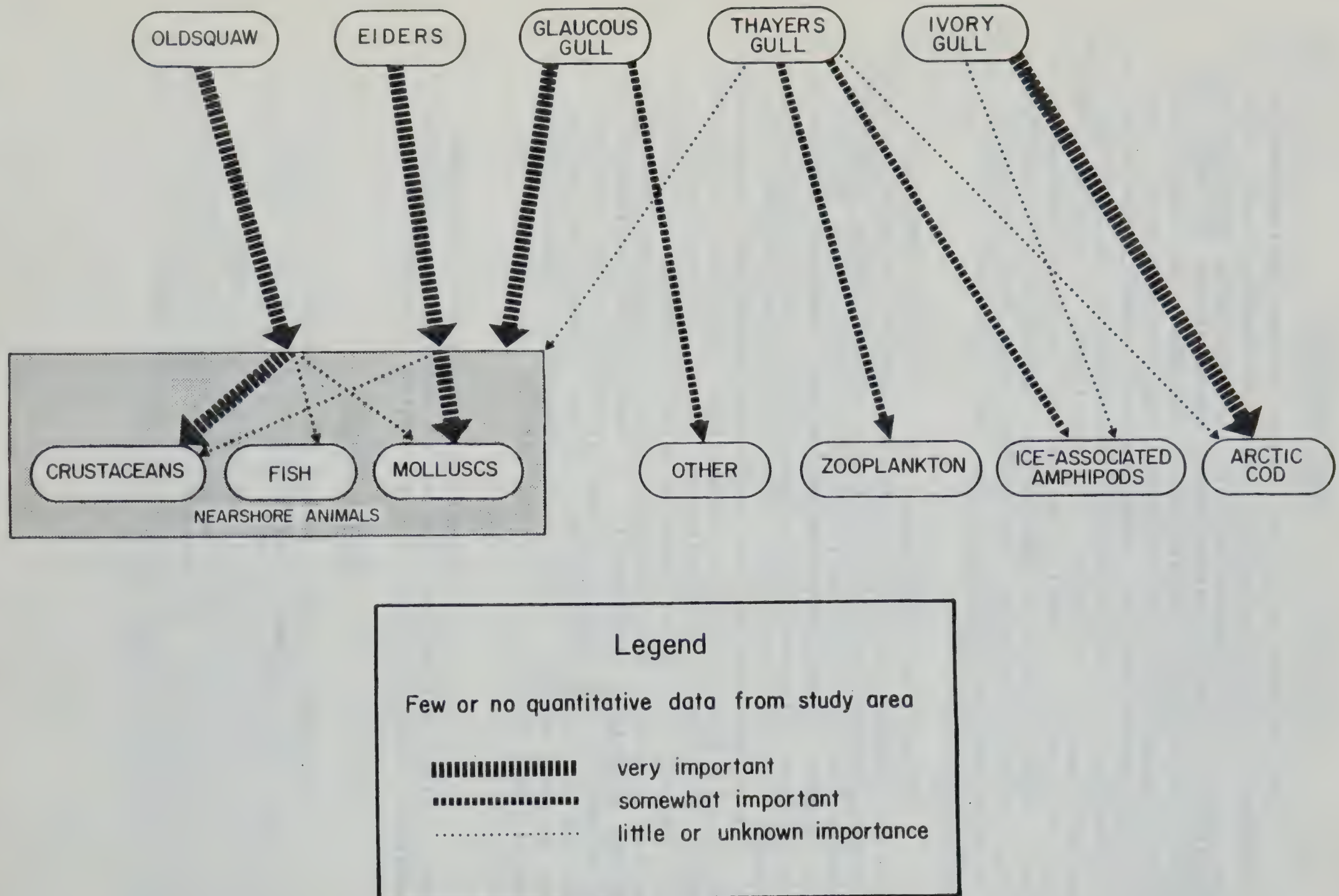


Figure 4-84

Aspects of the Importance of Arctic Cod to Various Seabirds During the Chick-rearing period.[1]

4.2.9.2.1 Seals

Three species of seal (ringed, bearded and harp) occur commonly in the area. McLaren (1958) reported that in shallow nearshore waters of southern Baffin Island, ringed seals fed on or near the bottom--chiefly on arctic cod, mysids and decapods. However, McLaren noted that over deep water, ringed seals fed pelagically, particularly on the amphipod _Parathemisto libellula_. Finley (1978) obtained similar results near Bathurst Island. However, Vibe (1950) found just the opposite near Thule, Greenland. There, ringed seals fed on arctic cod in deep waters, whereas amphipods and decapods were the principal foods near coasts.

In the Bering and Chukchi seas bearded seals were found to be almost entirely epibenthic feeders (Johnson _et al._, 1966; Burns, 1967; Kosygin, 1976). The diet is quite variable, but crabs, shrimps and molluscs dominated. Kosygin found 30 species of crustaceans, about 7 molluscs, 4 annelids and 15 fish in the stomachs he examined. Burns (1967) found that arctic cod assumed greater importance in the diets of the more northerly-collected animals. Near Thule, Greenland, Vibe (1950) reported that bearded seals are normally omnivorous benthic feeders but will utilize arctic cod if water depths are too great for the seals to reach the bottom.

Sergeant (1973b) reported the frequency of occurrence of various food items in a collection of 16 harp seals from the eastern Canadian Arctic. In descending order of frequency, important food taxa were arctic cod, mysids, amphipods (primarily _Parathemisto libellula_) and euphausiids. There are a few other reports of arctic cod and other fish in stomachs of harp seals in the eastern arctic.

4.2.9.2.2. Walrus

Mansfield (1973) concluded that the diet of walruses was principally clams, especially _Mya truncata_ and _Serripes groenlandicus_, but that walruses would eat a variety of epibenthic invertebrates and fish if clams were unavailable. Clams dominate the diet in Greenland and Alaskan waters as well as in the Canadian eastern arctic (Vibe, 1950; Mansfield, 1958; Fay _et al._, 1977).

4.2.9.2.3 Whales

Two whales, the beluga and narwhal, are abundant in Lancaster Sound; bowhead whales also occur in the area. The bowhead is a baleen whale, and feeds by straining small animals from large volumes of water. Brown (1868) and Mitchell

(1975) reported that zooplankton, including copepods, pteropods and amphipods, were important components of the bowhead's diet. However, in the western arctic various benthic animals (gammarid amphipods, mysids, sculpins, polychaetes, gastropods, etc.) as well as zooplankton have been found in bowhead stomachs (Johnson et al., 1978). This suggests that these whales sometimes feed near or on the bottom, at least in nearshore waters.

Qualitative assessments of the diet of narwhal indicate that arctic cod, squid, decapod crustaceans and Greenland halibut are taken. Sergeant and Hay (1977) reported that 50% of the food of narwhals at the Pond Inlet ice-edge was arctic cod. Other important components of the narwhal's diet were pelagic shrimp (Pasiphaea sp.) and squid (Gonatus fabricii). More detailed information will be forthcoming when contents of stomachs obtained in 1978 have been examined. Vibe (1950) reported the importance of arctic cod in the narwhal's diet near Thule, Greenland.

The beluga feeds on a wide variety of fish and invertebrates of benthic and pelagic origin (Kleinenberg et al., 1964), but in arctic waters arctic cod appear to be very important. The stomachs of two belugas from Allen Bay, Cornwallis Island, contained mostly arctic cod (Finley, 1976). Vibe (1950) found that belugas near Thule fed exclusively on cod and halibut. According to both Kleinenberg et al. (1969) and Finley (1976), belugas eat several foods in addition to cod--mainly nearshore animals and cephalopods--but the relative importance of these items in the diet is low.

4.2.9.2.4. Polar Bear

Polar bears feed predominantly on the ringed seal (Stirling and McEwan, 1975), but also frequently take the much larger bearded seal (Stirling and Archibald, 1977). If suitable ice persists, polar bears remain on sea ice and hunt seals throughout the year; however, in areas of ice-free sea the diet of shore-based polar bears varies considerably but often includes vegetation and carrion (Russell, 1975).

Based on the information cited above, suspected trophic relationships for marine mammals in nearshore and offshore waters are presented in Figure 4-85.

4.2.9.3 Marine and Anadromous Fish

4.2.9.3.1 Arctic Cod

Food items of arctic cod (Boreogadus saida) from the Russian Arctic include copepods, small bottom crustaceans

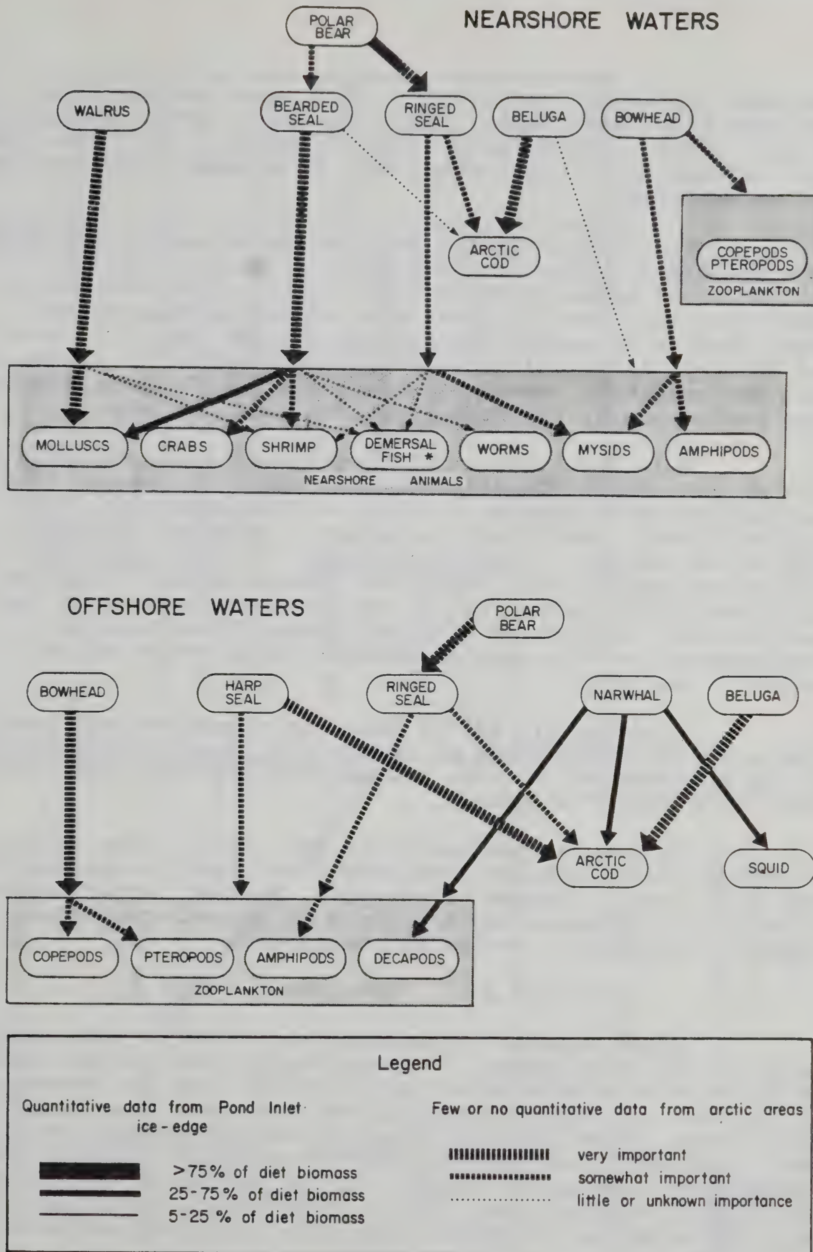


Figure 4-85

Suspected Trophic Relationships of Some Marine Mammal Species that are Present in Eastern Lancaster Sound.

(shrimp, larvaceans, amphipods), fish eggs, and young-of-the-year fish (Andriashev, 1954; Hognestad, 1968; Kleinenberg et al., 1969). Ponomarenko (1967) found that cod larvae and fry, as they grew, fed successively on copepod eggs, nauplii and copepodites.

Few studies of the food habits of arctic cod have been performed in the Canadian Arctic. Bain et al. (1977) qualitatively examined the stomachs of 13 young-of-the-year arctic cod collected in June from Wellington Channel and found them to be eating diatoms and copepod nauplii. Bohn and McElroy (1976) collected 83 juvenile and adult arctic cod from the nearshore bottom of Strathcona Sound; these fish had been eating mostly copepods, amphipods and decapods.

Bain and Sekerak (1978) quantitatively examined the diet of 252 arctic cod of lengths 50-300 mm collected in shallow nearshore waters of Allen and Resolute Bays, Cornwallis Island. Nearshore crustaceans--Onisimus Litoralis (60% of wet weight), Gammarus setosus (5%) and Mysis spp. (5%)--were particularly important (Figure 4-86). Craig and Griffiths (1978) noted that in the nearshore waters of the Beaufort Sea, arctic cod also fed primarily on nearshore crustaceans, particularly on mysids (71% of observed wet weight in the diet).

Frost et al. (1978) found that copepods and amphipods were important foods of arctic cod from offshore waters of the northeastern Chukchi and western Beaufort Seas during August and early September.

In summer, the available data from a wide variety of arctic areas indicate that larval cod feed on diatoms and the early (small) stages of copepods, whereas larger cod feed primarily on copepods and a variety of larger crustaceans including amphipods, mysids and decapods.

4.2.9.3.2 Sculpins

Eight species of sculpins are known or suspected to occur in the study area. No quantitative data on the diets of sculpins in the Canadian Arctic exist although Sekerak et al. (1976a) provide information that indicates that nearshore crustaceans (especially O. litoralis and G. setosus) were the most important food taxa to fourhorn sculpins collected in Creswell Bay, Somerset Island. In the nearshore waters of the Alaskan Beaufort Sea, Craig and Griffiths (1978) found that the observed wet-weight diet of 35 fourhorn sculpins

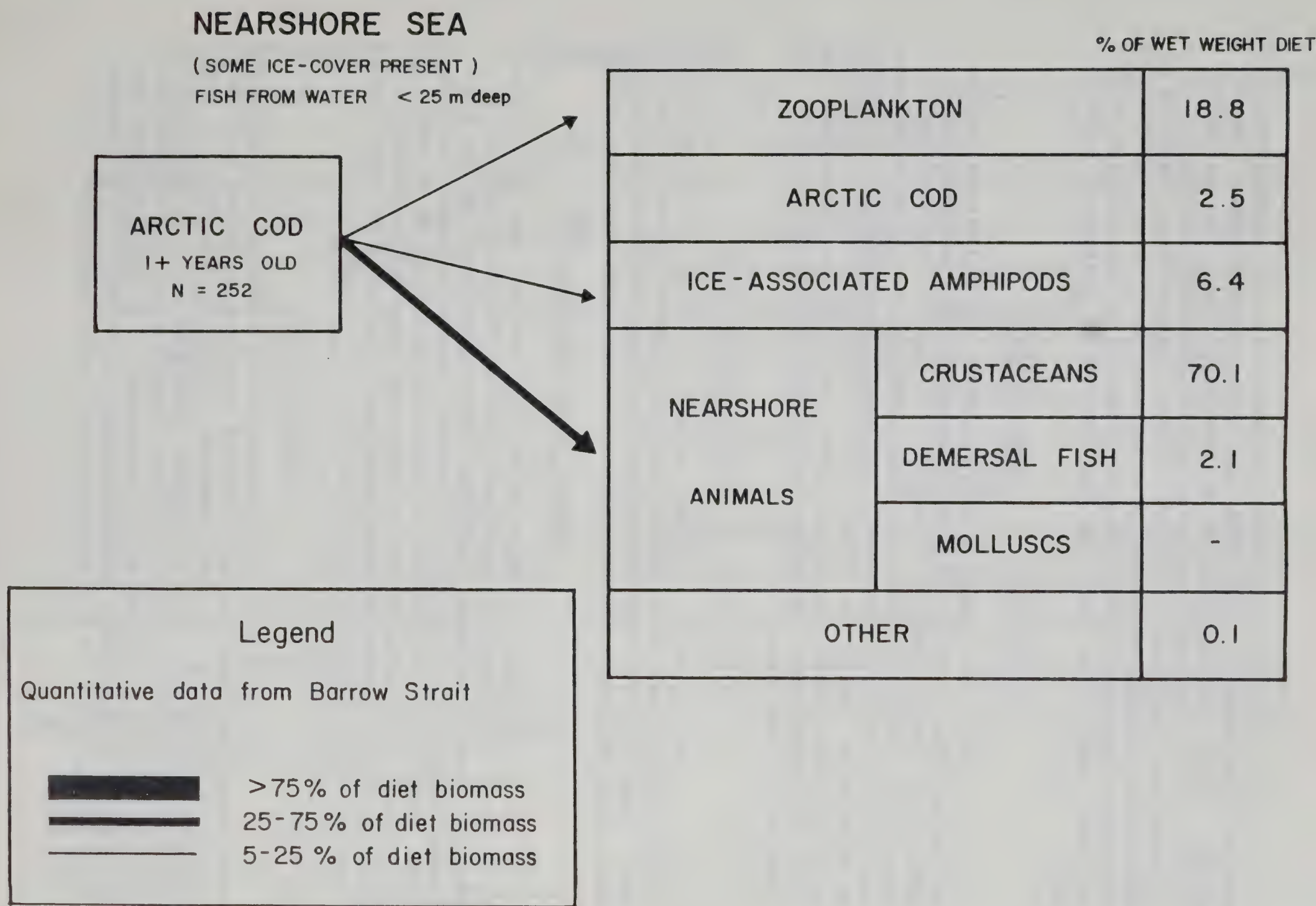


Figure 4-86

Food-web Relationships of Arctic Cod from Nearshore Waters of Barrow Strait (Bain and Sekerak, 1978).

collected during the open-water season was 43% amphipods, 33% mysids, 12% isopods, 10% fish and 3% unidentifiable. Frost et al. (1978) collected five of the eight sculpin species suspected to occur in Lancaster Sound from the bottom of the Alaskan Beaufort Sea in waters 50-130 metres deep; benthic or epibenthic animals were the predominant food items in the specimens examined. Thus fourhorn sculpins and perhaps other sculpins feed on or near the sea bottom on nearshore animals.

4.2.9.3.3 Arctic Char

Moore and Moore (1974) present quantitative information on the diet of anadromous char in the nearshore sea of Cumberland Sound, Baffin Island, in August. The diet of older char (8+years old) was comprised primarily of zooplankton (Figure 4-87), especially *Parathemisto libellula*. Younger char also fed on sculpins. Sekerak et al. (1976a) qualitatively described char diets from Creswell Bay, Somerset Island, as being about equally comprised of nearshore and planktonic creatures.

4.2.9.3.4 Other Marine Fish

Very little is known about the food habits of other marine fish known or expected to occur in northwestern Baffin Bay. Most species are bottom dwellers and it is expected that they feed on benthic crustaceans or other benthic fish.

4.2.9.4 Marine Invertebrates

Only general aspects of the feeding habits of most arctic marine invertebrates are known. The few detailed studies that have been performed are emphasized in the following material. Due to the general nature of most information and the large numbers of species present, it is not practical to discuss or even name most species, and only the most abundant invertebrates that are important in food chains leading to vertebrates are discussed.

4.2.9.4.1 Zooplankton

The three major species of herbivorous zooplankters that serve as food for vertebrates are the pteropod mollusc *Limacina helicina* and two copepods, *Calanus hyperboreus* and *Calanus glacialis*. Lalli (1970) reported that *L. helicina* fed primarily on diatoms and dinoflagellates (phytoplankton) and on tintinnid ciliates (protozoans). *C. hyperboreus* and *C. glacialis* are both filter-feeding herbivores that, according to Mullin (1963), consume the larger species of phyto-

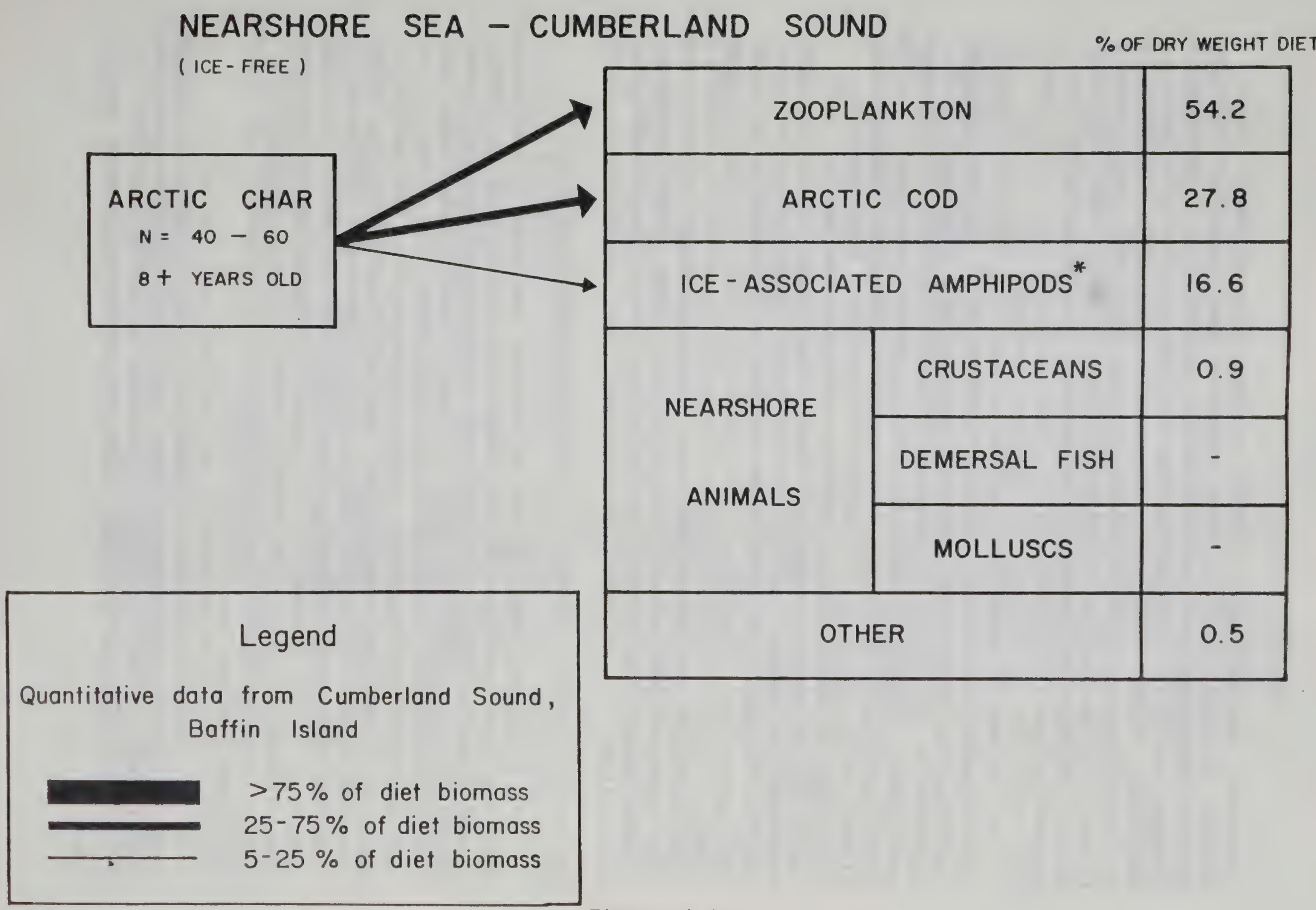


Figure 4-87

Trophic Relationships of Arctic Char from Nearshore Waters of Cumberland Sound (adapted from Moore and Moore, 1974). Since the area was ice-free, ice-associated amphipods were probably planktonic.

plankton. Bain *et al.*, (1977) showed that in Wellington Channel in spring, both these copepod species fed on phytoplankton species that were abundant, especially *Nitzschia grunowi* and *N. seriata*. During periods of phytoplankton scarcity, calanoid copepods may survive by some combination of (1) living on stored food reserves (Conover, 1962; Lee, 1974), (2) feeding on detritus (Poulet, 1976), and (3) feeding on crustaceans, radiolarians and other microorganisms (Marshall and Orr, 1962).

Carnivorous zooplankters that are important foods for vertebrates include the pteropod mollusc *Clione limacina* and hyperiid amphipods, mainly *Parathemisto libellula*. In the Arctic, *C. limacina* feeds exclusively on the herbivorous pteropod *L. helicina* (Lalli, 1970). Conover and Lalli (1972, 1974) have quantified the feeding rate and assimilation efficiency of *C. limacina* in temperate waters. *Parathemisto libellula* is carnivorous on other zooplankton and is very important in the transfer of food energy from lower (invertebrate) to higher (vertebrate) trophic levels (Dunbar, 1957). Copepods were the most commonly found food items in the guts of *P. libellula* collected off Baffin Island (Dunbar, 1946). Wing's (1976) detailed study of the feeding habits of this species in Alaska indicates that, although copepods were the dominant food items, chaetognaths, fish larvae, euphausiids, other crustaceans, polychaetes and phytoplankton were also eaten.

4.2.9.4.2 Ice-associated Amphipods

Several species of amphipods are closely associated with the undersurface of ice (fast ice or ice pans). The foods eaten by *Onisimus glacialis*, *Gammarus wilkitzkii* and *Apherusa glacialis* (the species most closely associated with the undersurface of the ice) are not known, but several authors have reported that many ice-associated amphipods graze on ice-algae (Apollonio, 1961; Alexander *et al.*, 1974; Horner, 1974; Welch and Kalff, 1975). However, the feeding habits of *Apherusa glacialis* may be quite different, for it occurs in large numbers on ice pans in summer when ice-algae are perhaps absent or extremely rare. *Gammaracanthus loricatus*, another ice-associated species, is predatory on other amphipods (Green and Steele, 1975).

When ice-cover is absent, *O. glacialis*, *A. glacialis* and some *G. wilkitzkii* occur planktonically, whereas most *G. wilkitzkii* and *G. loricatus* assume a benthic habitat. Their food habits in these circumstances are largely unknown.

4.2.9.4.3 Nearshore Animals

Nearshore benthonic marine invertebrates that are known to be important as food to vertebrates include various crustaceans, polychaetes and molluscs. Benthic crustaceans important to vertebrates include amphipods, mysids, decapods, isopods and some harpacticoid copepods. The major amphipods are *Onisimus litoralis*, *Anonyx* spp. and *Gammarus setosus*. Each of these species may sometimes be closely associated with the undersurface of ice in nearshore areas, and at such times it is thought that they graze on ice algae (Buchanan *et al*., 1977). In ice-free periods, *O. litoralis* is a scavenger on carrion (Steele, 1961), and a predator on disabled and perhaps healthy animals (MacGinitie, 1955; LGL Ltd. unpubl. data). *Anonyx nugax* is also usually classified as a benthic scavenger (Dunbar, 1954; MacGinitie, 1955; Green and Steele, 1975). *Gammarus setosus*, when occurring in ice-free nearshore waters, may be a grazer of algae films (Steele, 1961).

Mysids feed while swimming and collect food particles on their finely spaced setae. The feeding habits of arctic species have not been studied but mysids are known to feed on phytoplankton and suspended detritus in other regions.

Arctic decapods (and isopods) appear to be primarily detritus eaters (Squires, 1967), as are harpacticoid copepods (Brown and Sibert, 1977). Decapods may also eat other crustaceans and foraminifera (Squires, 1967).

Molluscs are important to several groups of vertebrates, particularly to eiders and walruses. Lubinsky (1972) noted that in arctic Canada 86% of the bivalve fauna are sedimentation (deposit) feeders (i.e. ingest the substrate). Many polychaetes and some bivalves are classed as filter feeders. Many filter feeders may utilize material of benthic (e.g., bacteria, phytobenthos) rather than of pelagic (e.g., phytoplankton) origin. Among the common filter-feeding molluscs are members of the genera *Astarte*, *Cardium*, *Mya*, *Mytilus*, *Serripes* and *Thirasira*; common deposit feeders are members of the genera *Macoma*, *Nucula*, *Nuculana*, *Portlandia* and *Yoldia* (Ockelmann, 1958).

4.2.9.5 Summary and Integration

Given the information presented in previous divisions of Section 4.2.9, it is possible to construct two preliminary summary food webs, one for nearshore waters (Figure 4-88) and one for offshore waters (Figure 4-89). The *preliminary* nature of these food webs must be stressed since data

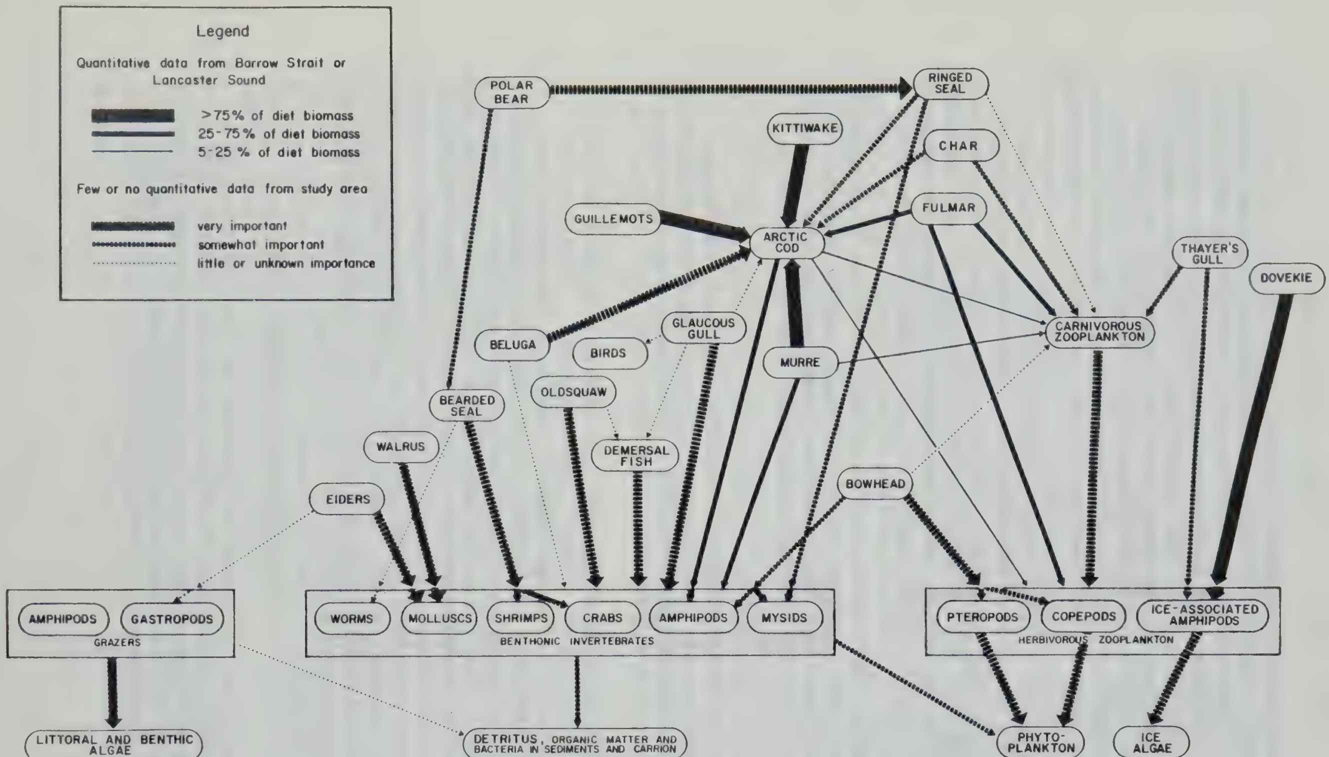


Figure 4-88
Preliminary Summary of Food-web Relationships in Nearshore Arctic Waters. Includes seabirds collected along landfast ice-edges.

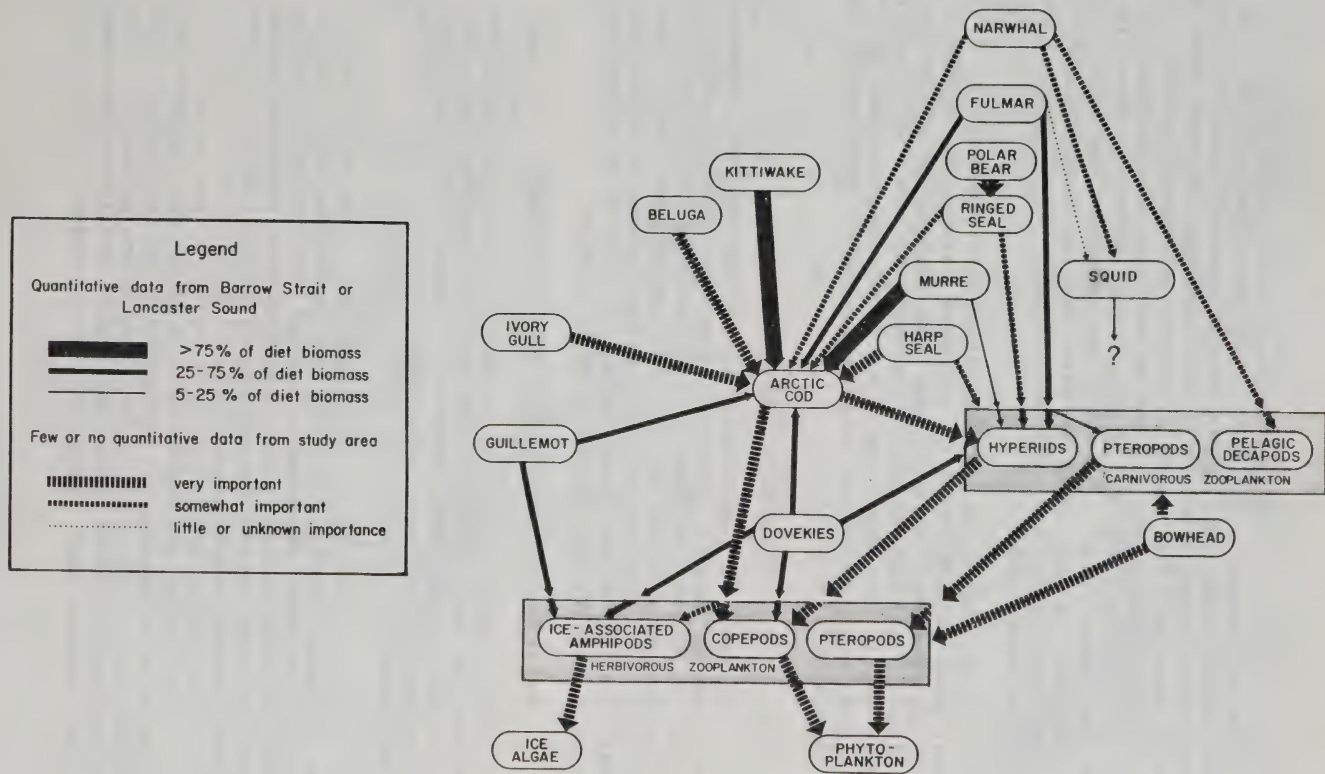


Figure 4-39
Preliminary Summary of Food-web Relationships in Offshore Arctic Waters. Includes seabirds collected from ice-edges over deep water.

on the food habits of some species are either qualitative, speculative or lacking. At times, information from studies in other arctic areas has been used to identify possibly important trophic pathways, but such information must also be used with caution. For example, eiders are known to eat primarily Mytilus edulis, a bivalve mollusc, in the Russian Arctic (East Murman) but M. edulis is not known to occur in eastern Lancaster Sound. It would be incorrect to apply the Russian results to the Canadian High Arctic; nevertheless, eiders may feed heavily on the shallowwater bivalves that do occur in the study area.

Food webs in nearshore waters are, generally speaking, more complex than in offshore waters due to the presence of benthonic animals that are accessible to marine vertebrates in shallow areas. Figures 4-88 and 4-89 clearly show that arctic cod are a key element in the transfer of energy from lower to higher trophic levels in both nearshore and offshore arctic waters.

4.2.10 On-going Studies

As part of the Eastern Arctic Marine Environmental Studies (EAMES) program, Petro-Canada commissioned a large series of biological studies in northwestern Baffin Bay. These studies were begun in 1978 and are planned to be continued in 1979. The results of the studies in 1978 are not yet available but brief descriptions of the major components of the 1978 program are given in this section.

4.2.10.1 Offshore Marine Ecology

The offshore marine ecology program was performed in conjunction with the offshore seabird feeding study and the physical oceanography program. Figure 4-90 illustrates the locations of the major biological stations occupied during the summer and early fall study period.

Approximately 55 major stations were occupied. During the study period (23 July to 10 October 1978) 24 of these stations were repeated at least three times, 17 twice and 14 once. In general, the stations were situated in a transect pattern perpendicular to the shoreline to provide inshore-offshore comparative data.

The major objective of the study was to provide baseline data on planktonic communities in the region. Thus, phytoplankton, zooplankton (including ichthyoplankton) and concentrations of chlorophyll and plant nutrients were monitored for seasonal and geographic differences. Phytoplankton

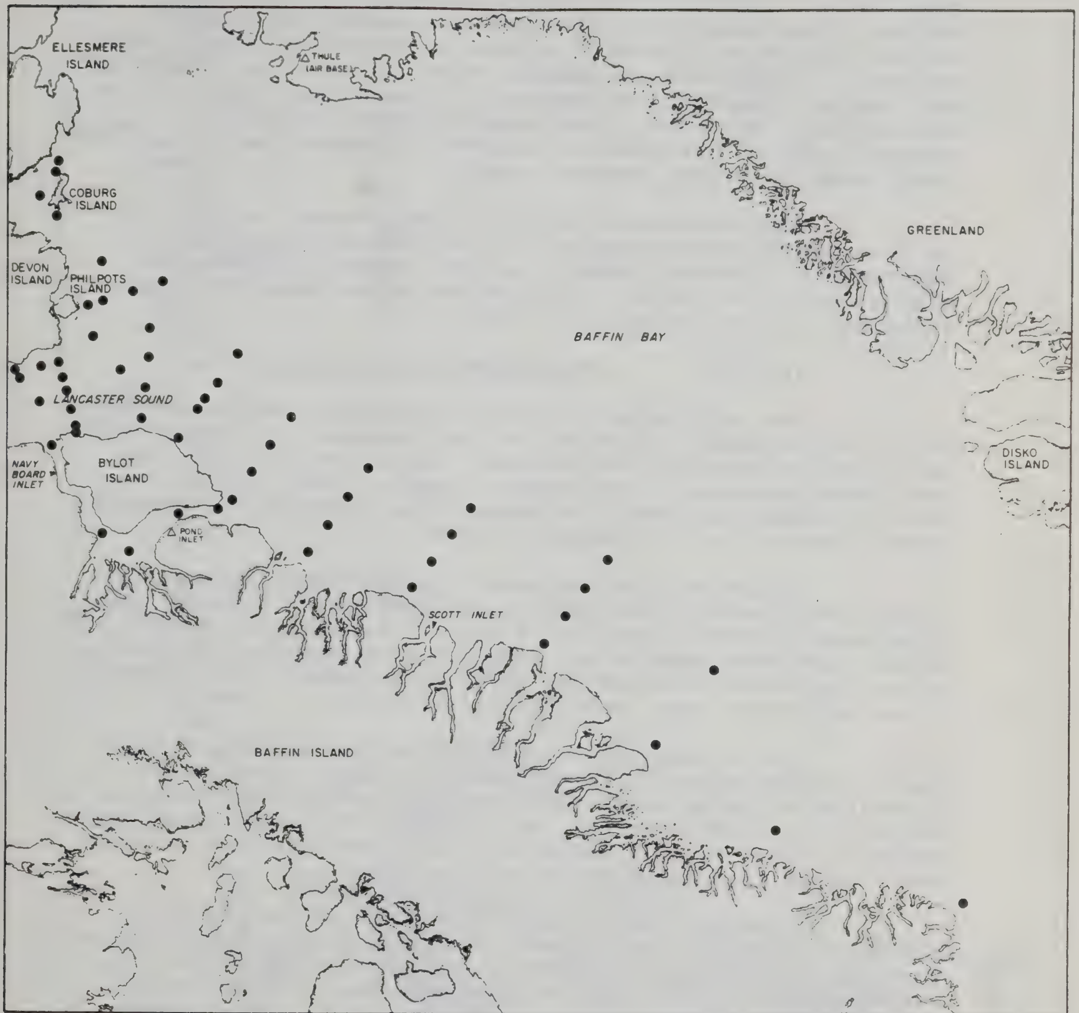


Figure 4-90

Approximate Locations of Offshore Stations Occupied During 1978.

sampling was mainly in the upper 50 metres of the water column. Quantitative collections of zooplankton were obtained throughout the water column in waters as deep as 2000 metres. Ichthyoplankton samples were collected at intervals to a maximum depth of 170 metres. In addition, quantitative samples for deep water (from approximately 50 to 1100 m depths) benthic fauna were collected to extend the depth range sampled in the inshore study.

Some assessment of the 'year-to-year' variability in planktonic communities will be available since three of the eastern Lancaster Sound stations sampled in 1978 were also occupied during the Norlands Petroleum Ltd. 1976 study (reported in Sekerak et al., 1976b).

4.2.10.2 Nearshore Marine Ecology

The main objective of the nearshore marine ecology study was to typify the biota of the dominant geological features of the seashore and seabed. The study sites (Figure 4-91) were selected to provide a range of beach types, exposure to waves, and substate types. The study period extended from 17 August to 21 September, 1978.

Intertidal and infaunal benthic sampling were performed concurrently with geological sampling. Infaunal benthic samples were taken with a grab. Quantitative intertidal collections were made along the shoreline with measurements of appropriate environmental variables. Otter trawls, long lines and divers were used to collect fish.

One of the main components of the nearshore work was a shallow water study conducted by SCUBA divers using quantitative techniques. The diving effort concentrated on collections of macrophytes, epibenthic animals, infauna, and animals living on rock surfaces. This operation was closely coordinated with a geological diving study.

Plankton and nutrient sampling was performed in nearshore waters to supplement the offshore sampling efforts. Samples were taken off the Philpots and Cape Warrender glaciers, Cape Sherard, Cape Hay, Erik Harbour, Clarke Fjord, Scott Inlet, and Oliver Sound (Figure 4-91). Zooplankton, phytoplankton, plant nutrients and fish larvae were sampled at most locations. Marine mammal and seabird observations were made routinely throughout the study period. These observations were coordinated with the offshore study and the aerial surveys of birds and marine mammals.

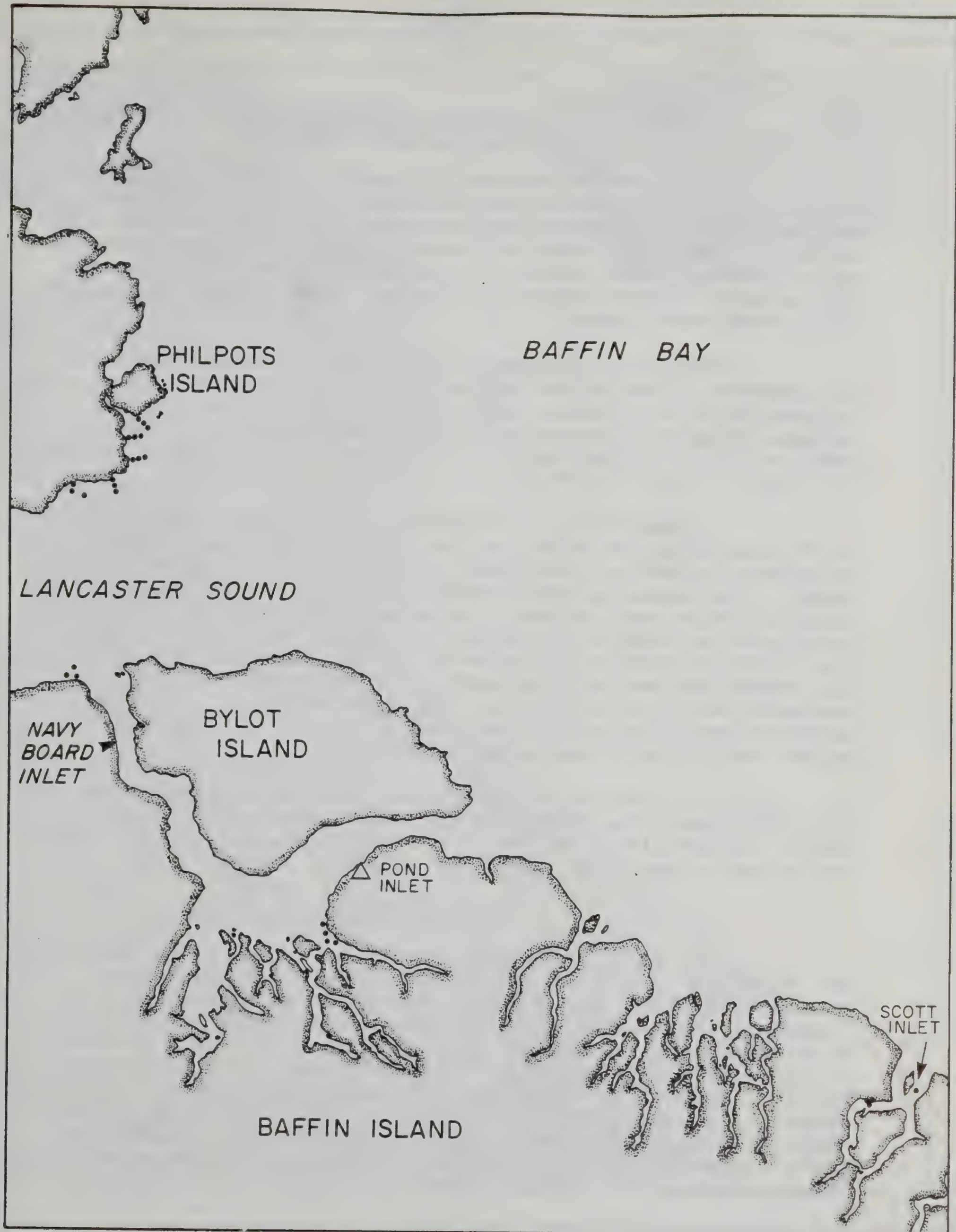


Figure 4-91

Approximate Locations of Inshore Stations Occupied During 1978.

4.2.10.3 Numbers, Distribution and Movements of Birds and Mammals

An intensive program of aerial surveys was conducted in 1978 to determine the distributions and migrations of sea-associated birds and marine mammals in northwestern Baffin Bay. The study area is shown in Figure 4-92. Systematic aerial surveys were flown at approximately weekly intervals (23 surveys) from 4 May to 10 October 1978. Over 77,000 km of surveys were flown.

The survey design varied with ice-conditions and with season. The survey rationale is not discussed here. As an example of the design used and the type of results obtained, Figures 4-93 and 4-94 show the distribution of one species (Thick-billed Murre) during one of the weekly surveys (26 June - 1 July 1978).

In addition to the main survey program exemplified in Figures 4-93 and 4-94, aerial surveys of other areas were conducted to address specific questions of biological importance. For example, the 'Baffin Bay North Water' was surveyed in March and in April to assess the numbers of mammals overwintering there. A series of transects was flown over the offshore pack ice in mid-Baffin Bay east of Pond Inlet to determine the use of this habitat by migratory narwhals and bowheads and by ringed seals. Various areas of landfast ice were surveyed during the haul-out season of ringed seals to assess their distribution and numbers.

The results of the aerial surveys were supplemented with systematic observations of seabirds made from ships, of birds and mammals from the Pond Inlet ice-edge, and of autumn whale migrations from Cape Adair, Baffin Island.

4.2.10.4 Feeding Ecology of Seabirds

The feeding ecology of selected species of seabirds was examined by stomach analysis of collected specimens. Species and areas sampled were chosen to supplement the studies of Bradstreet (1976, 1977) in Lancaster Sound and Barrow Strait. Additional specimens were obtained from Inuit at the Pond Inlet ice-edge. Supplementary information was obtained through observations of feeding behaviour at sea and behaviour at major nesting colonies. The results of these studies will be integrated with the distribution data from aerial surveys and the biological and physical oceanographic components of the EAMES program.

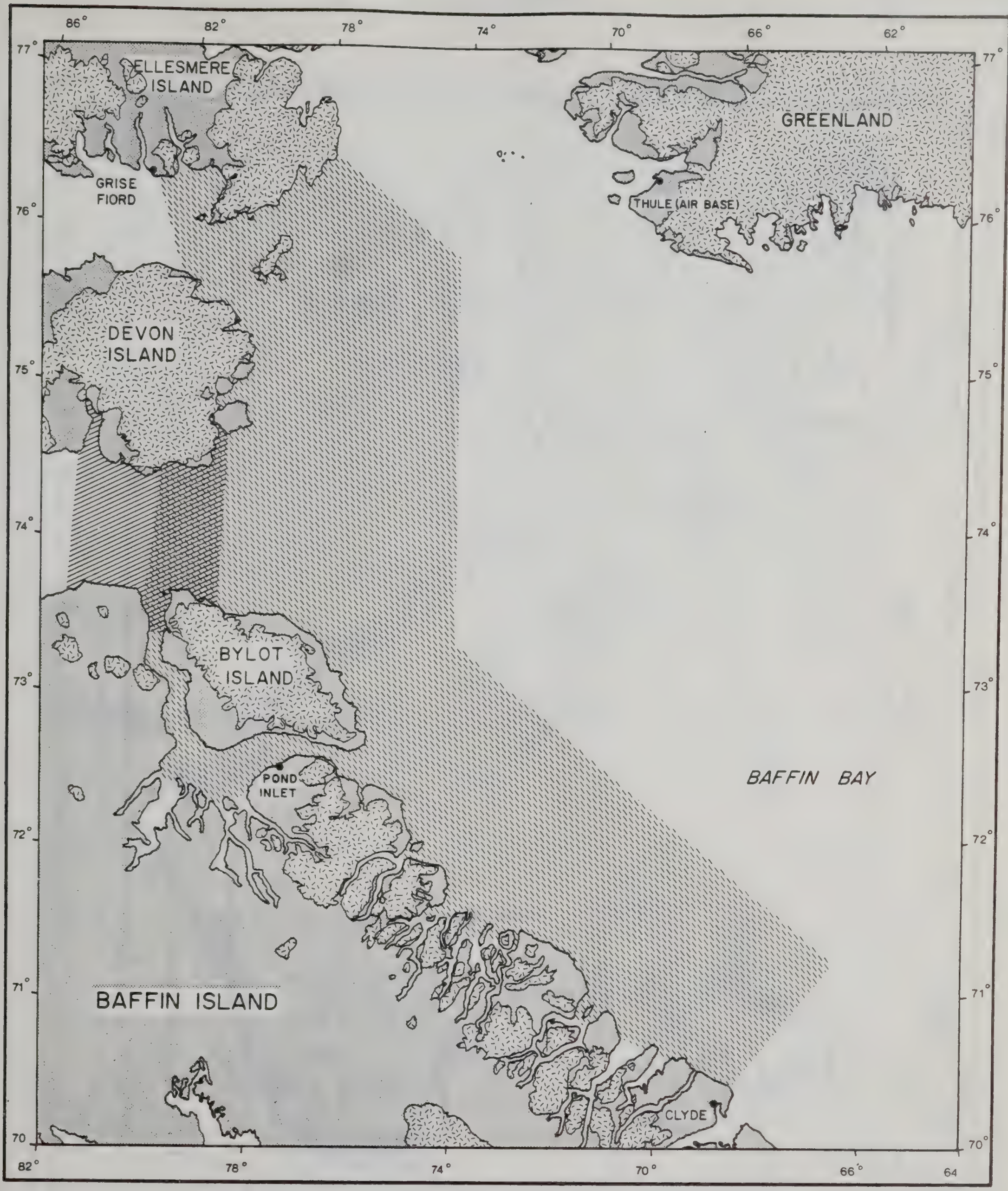


Figure 4-92
Areas Surveyed for Seabirds and Marine Mammals in 1976 (solid hatching) and 1978 (broken hatching).

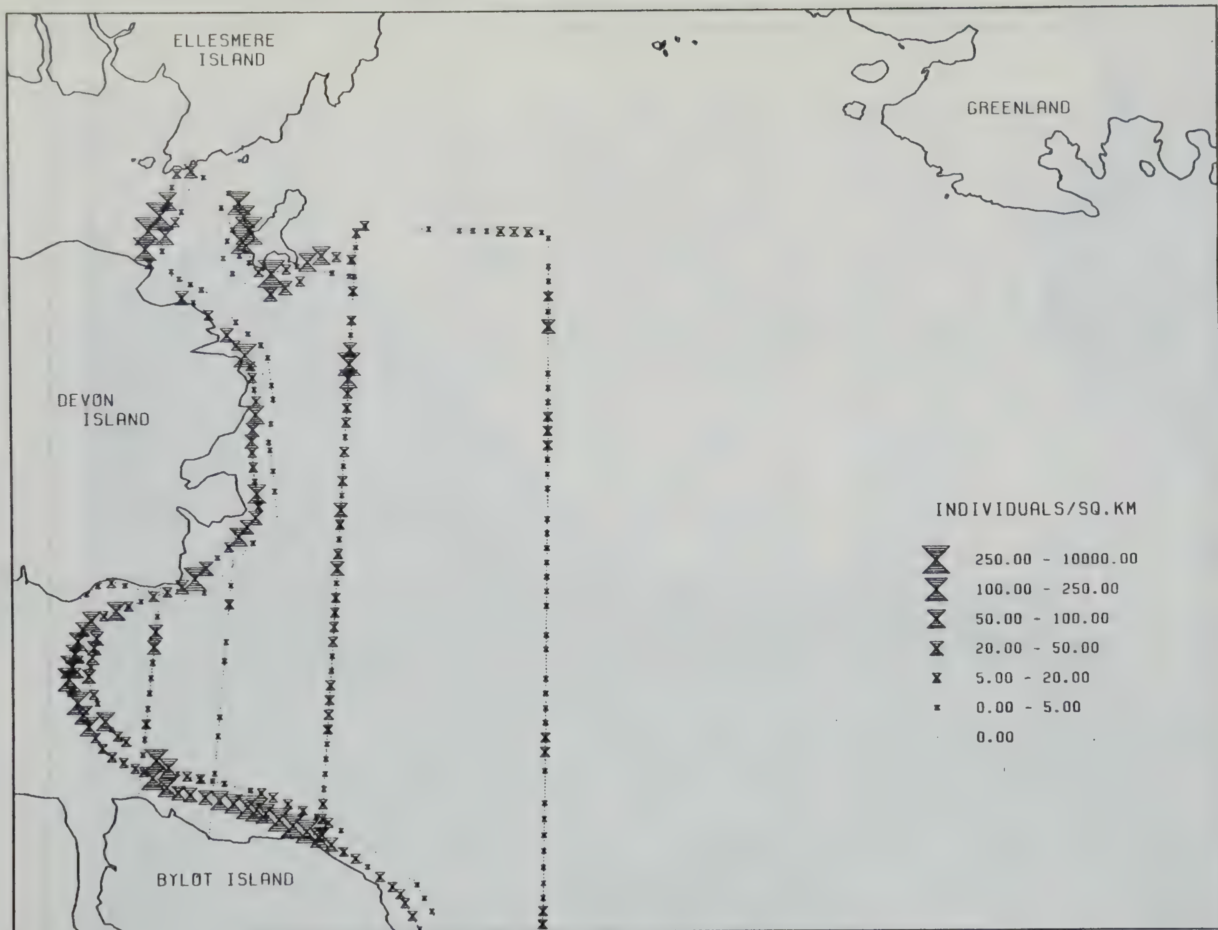


Figure 4-93

Distribution of Thick-billed Murres in the Northern Half of the Study Area, 26 June - 1 July 1978.

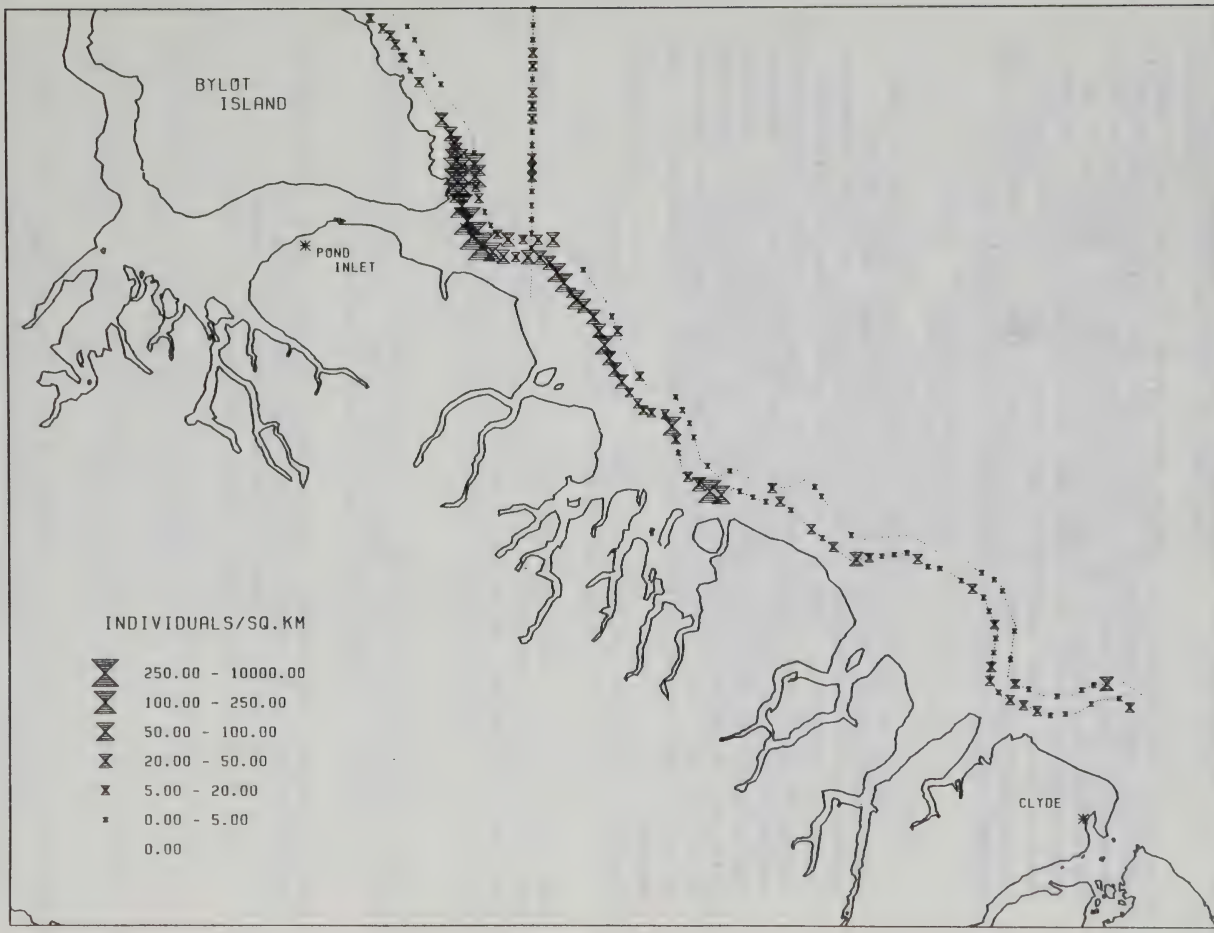


Figure 4-94

Distribution of Thick-billed Murres in the Southern Half of the Study Area, 26 June - 1 July 1978.

4.2.10.5 Biology of Marine Mammals

Stomachs and tissue specimens from marine mammals taken by Inuit hunters at Pond Inlet and Grise Fjord were obtained. These samples will be analyzed to determine diet, reproductive status and age of the animals. Results from these analyses will be combined with interviews of hunters, observations from ice-edges and boats, and the results of aerial surveys to clarify the distribution and movements of mammals and to examine important trophic relationships.

4.2.10.6 Seabird Colonies

The EAMES program included brief studies at the seabird colonies at Coburg Island and Cape Hay. These studies were conducted jointly by LGL Ltd. and the Canadian Wildlife Service. The unusual ice conditions in Lancaster Sound in 1978 had the potential to greatly affect the nesting success, behaviour and distribution of seabirds. To assess the potential effects, Petro-Canada funded Dr. D.N. Nettleship of Canadian Wildlife Service to continue his three-year study of the breeding biology of seabirds at Prince Leopold Island. Polar Continental Shelf Project provided additional support.

REFERENCES

Alexander, V. 1974. Primary productivity regimes of the near-shore Beaufort Sea, with reference to the potential roles of ice biota. In: J.C. Reed and J.E. Sater (eds.), The coast and shelf of the Beaufort Sea. AINA 609-632.

Alexander, V., Horner, R. and Clasby, R.C. 1974. Metabolism of arctic sea ice organisms. University of Alaska, Inst. Mar. Sci. Rept. No. R74-4. 120 p.

Alison, R.M. 1972. The breeding biology of the Oldsquaw (Clangula hyemalis L.) at Churchill, Manitoba. Unpubl. Ph.D. Thesis, University of Toronto, Toronto, Ontario. 120 p.

Alliston, W.G., Bradstreet, M.S.W., McLaren, M.A. Davis, R.A. and Richardson, W.J. 1976. Numbers and distribution of birds in the central District of Franklin, N.W.T. June-August, 1975. Unpubl. Rept. by LGL Ltd. to Polar Gas Project. 584 p.

Anders, G. (ed.). 1967. Baffin Island - East Coast: An area economic survey. Dept. of Indian Affairs and Northern Development, Industrial Division. 196 p.

Andrew, J.T., Buckley, J.T. and England, J.H. 1970. Late Glacial Chronology and Glacio-Isostatic Recovery, Home Bay, East Baffin Island, Canada; Geological Society of America Bulletin Vol. 81, No. 4 April 1970. pp. 1123-1148.

Andriashev, A.P. 1954. Fishes of the northern seas of the U.S.S.R. Zool. Inst. Acad. Sci. Leningrad. (Israel Program Sci. Transl. No. 836, 1964). 617 p.

Andriashev, A.P. 1970. Cryopelagic fishes of the Arctic and Antarctic and their significance in polar eco-systems. In: W.H. Holdgate (ed.), Antarctic ecology, Vol. 1. Academic Press, New York. pp.297-304.

Apollonio, S. 1961. The chlorophyll content of arctic sea ice. Arctic 14: 197-200.

Apollonio, S. 1965. Chlorophyll in arctic sea ice. Arctic 18: 118-122.

Atlas, R.M., Horowitz, A.and Busdosh, A. 1978. Prudhoe crude oil in Arctic marine ice, water, and sediment ecosystems: Degradation and interactions with microbial and benthic communities. J. Fish. Res. Board Can. 35: 585-590.

B.C. Research. 1975. Baseline survey of the marine environment at Strathcona Sound, N.W.T. Progress Report No. 1, Unpubl. Rept. to Strathcona Mineral Serv. 84 p.

Bain, H. and Sekerak, A.D. 1978. Aspects of the biology of Arctic cod, Boreogadus saida, in the central Canadian Arctic. Unpubl. Rept. by LGL Ltd. for Polar Gas Project. 104 p.

Bain, L.H., Thomson, D., Foy, M., and Griffiths, W. 1977. Marine ecology of fast-ice edges in Wellington Channel and Resolute Passage, N.W.T. Unpubl. Rept. by LGL Ltd. to Polar Gas Project. 262 p.

Baker, Seymour R., Friedman, Gerald M., 1973. Sedimentation in an Arctic Marine Environment: Baffin Bay Between Greenland and the Canadian Arctic Archipelago: Earth Science Symposium on Offshore Eastern Canada; Geological Survey Can., paper 71-23; 1973 p. 471-498.

Barnett, D.M., 1967. Development, Landforms and Chronology of Generator Lake, Baffin Island, N.W.T. Geographic Bulletin Vol. 9, No. 3 1967.

Barry, T.W. 1968. Observations on natural mortality and native use of eider ducks along the Beaufort Sea coast. Can. Field-Nat. 82: 140-144.

Basham, P.W., Forsyth, D.A. and Wetmiller, R.T. 1977. The seismicity of northern Canada. Can. J. Earth Sci., (14): 1646-1667.

Beck, B. and Mansfield, A.W. 1969. Observations on the Greenland shark (Somniosus microcephalus) in northern Baffin Island. J. Fish. Res. Board Can. 26: 143-145.

Bellrose, F.C. 1976. Ducks, geese and swans of North America. Stackpole Books, Harrisburg, Pa. 544 p.

Belopol'skii, L.O. 1957. Ecology of sea colony birds of the Barents Sea. English transl. by Israel Program for Sci. Transl., Jerusalem. 346 p.

Birkhead, T.R. 1974. Movement and mortality rates of British guillemots. Bird Study 21: 241-254.

Birkhead, T.R. and Hudson, P.J. 1977. Population parameters for the Common Guillemot Uria aalge. Ornis Scan. 8: 145-154.

Bissett, D. 1967. Northern Baffin Island. An area economic survey. Vol. 2. A.E.S.R. 67/1. 131 p.

Blackadar, R.G., 1956. Geological Reconnaissance of Admiralty Inlet, Baffin Island, Arctic Archipelago, N.W.T., Geol. Surv. Can. paper 55-6; 1956.

Blackadar, R.G., 1967. Geological Reconnaissance, Southern Baffin Island, District of Franklin; Geol. Surv. Can. paper 66-47, 1967.

Blackadar, R.G., 1965. Geological Reconnaissance of the Precambrian of Northwestern Baffin Island, Northwest Territories; Geol. Surv. Can. paper 64-42, 1965.

Blackadar, R.G., 1967. Geology of Mingo Lake - Macdonald Island Map - Area, Baffin Island, Distrist of Franklin; Geol. Surv. Can. memoir 345, 1967.

Blackadar, R.G., 1970. Precambrian Geology Northwestern Baffin Island, District of Franklin; Geol. Surv. Can. Bulletin 191; 1970.

Blake, W., Jr., 1966. End Moraines and Deglociation Chronology in Northern Canada with special reference to Southern Baffin Island; Geol. Surv. Can. paper 66-26; 1966.

Bohn, A. and McElroy, R.O. 1976. Trace metals (As, Cd, Cu, Fe and Zn) in Arctic cod, Boreogadus saida, and selected zooplankton from Strathcona Sound, northern Baffin Island. J. Fish. Res. Board Can. 33: 2836-2840.

Bostock, H.S., 1964. A Provisional Physiographic Map of Canada; Geol. Surv. Can. paper 64-35, 1964.

Bowman, T.E., 1960. The pelagic amphipod genus Parathemisto (Hyperiidea: Hyperiidae) in the North Pacific and adjacent Arctic Ocean. Proc. U.S. Nat. Mus. 112: 343-392.

Bradstreet, M.S.W. 1976. Summer feeding ecology of seabirds in eastern Lancaster Sound, 1976. Unpubl. Rept. by LGL Ltd. to Norlands Petroleums Ltd. 187 p.

Bradstreet, M.S.W. 1977. Feeding ecology of seabirds along fast-ice edges in Wellington Channel and Resolute Passage, N.W.T. Unpubl. Rept. by LGL Ltd. to Polar Gas Project. 149 p.

Brodie, P.F. 1969. Mandibular layering in Delphinapterus leucas and age determination. Nature (London) 221: 956-958.

Brown, R. 1868. Notes on the history and geographical relations of the Cetacea frequenting Davis Strait and Baffin's Bay. Proc. Zool. Soc. London 1868: 553-556.

Brown, R.G.B., Nettleship, D.N., Germain, P., Tull, C.E. and T. Davis. 1975. Atlas of eastern Canadian seabirds. Can. Wildl. Serv., Ottawa. 220 p.

Brown, T.J. and Siebert, J.R. 1977. Food of some benthic harpacticoid copepods. J. Fish. Res. Board Can. 34: 1028-1031.

Buchanan, R.A. 1975. Marine epifaunal communities on test plates: Newfoundland to South Carolina. M.Sc. Thesis, McGill University, Montreal. 183 p.

Buchanan, R.A., Cross, W.E. and Thomson, D.H. 1977. Survey of the marine environment of Bridport Inlet, Melville Island. Unpubl. Rept. by LGL Ltd. to Petro-Canada. 265 p.

Budinger, T.F., 1960. Wind Effect on Icebergs (U.S. Coast Guard, unpublished manuscript).

Bunch, J.N. 1974. Distribution and abundance of heterotrophic bacteria on the South Beaufort Sea. Environmental Social Committee Northern Pipelines, Task Force on Northern Oil Devel. Rept. No. 74-22: 175-191.

Bunch, J.N. and Harland, R.C. 1976. Biodegradation of crude petroleum by the indigenous microbial flora of the Beaufort Sea. Beaufort Sea Tech. Rept. No. 10. 52 p.

Bunt, J.S. 1963. Diatoms of antarctic sea-ice as agents of primary production. Nature 199: 1255-1257.

Bunt, J.S. 1964. Primary productivity under sea-ice in antarctic waters. 2. Influence of light and other factors on phytosynthetic activities of antarctic marine microalgae. In: M.O. Lee (ed.), Biology of Antarctic seas III, Antarctic Research Series, Vol. 1: 27-31.

Burns, J.J. 1967. The Pacific bearded seal. Alaska Dept. of Fish and Game, Juneau. 66 p.

Bursa, A.S. 1961a. Phytoplankton of the Calanus expeditions in Hudson Bay, 1953 and 1954. J. Fish. Res. Board Can. 18: 51-83.

Bursa, A.S. 1961b. The annual oceanographic cycle at Igloolik in the Canadian Arctic. II. The phytoplankton. J. Fish. Res. Board Can. 18: 563-615.

Bursa, A.S. 1971. Biological oceanographic observations in Frobisher Bay. III. Phytoplankton tables, 1967. Fish. Res. Board Can. Tech. Rept. No. 267. 21 p.

Canadian Hydrographic Service (1970), Pilot Arctic Canada, Vol. 1, 247 pp.

Canadian Oceanographic Data Centre (1966). Arctic 1961, August 2 to October 12, 1961. Data record series No. 12. 322 pp.

Canadian Wildlife Service 1972. Arctic Ecology Map Series, Descriptive Reports. Second Edition. 324 p.

Chari, T.R., Guha, S.N. 1978. A model study of iceberg scouring in the North Atlantic. Offshore Technol. Conf., Paper 3316.

Christensen, O. and Lear, W.H. 1977. Bycatches in salmon drift-nets at West Greenland in 1972. Meddelelser om Gronland 205: 1-38.

Church, M., 1972. Baffin Island Sondurs: A Study of Arctic Fluvial Processes; Geol. Surv. Can. Bulletin 216, 1972.

Clarke, M.R. 1962. The identification of cephalopod 'beaks' and the relationship between beak size and total body weight. Bull. Brit. Mus. Zool. 8: 421-480.

Collin, A.E. 1962. The oceanography of Lancaster Sound. Ph. D. Thesis, McGill University, Montreal. 204 p.

Conover, R.J. 1962. Metabolism and growth in Calanus hyperboreus in relation to its life cycle. Rapp. P.-v. Reun. Cons. Perm. Int. Explor. Mer 153: 190-197.

Conover, R.J. and Lalli, C.M. 1972. Feeding and growth in Clione limacina (Phipps), a pteropod mollusc. J. Exp. Mar. Biol. Ecol. 9: 279-302.

Conover, R.J. and Lalli. C.M. 1974. Feeding and growth in Clione limacina (Phipps) a pteropod mollusc. II. Assimilation, metabolism and growth efficiency. J. Exp. mar. Biol. Ecol. 16: 131-154.

Coulson, J.C. 1966. The influence of the pair-bond and age on the breeding biology of the Kittiwake Gull Rissa tridactyla. J. Anim. Ecol. 35: 269-279.

Coulson, J.C. and Wooller, R.D. 1976. Differential survival rates among breeding Kittiwake Gulls (Rissa tridactyla L.). J. Anim. Ecol. 45: 205-213.

Craig, B.G., 1965. Notes on Moraines and Radiocarbon Dates in Northwest Baffin Island, Melville Peninsula, and Northeast District of Keewatin, Geol. Surv. Can. paper 65-20, 1965.

Craig, B.G. and Fyles, J.G., 1960. Pleistocene Geology of Arctic Canada Geol. Surv. Can. paper 60-10.

Craig, P.C. and Griffiths 1978. Annual report, Beaufort Sea barrier island-lagoon ecological process studies: Ecology of fishes in Simpson Lagoon, 1977. Unpubl. Rept. by LGL Ltd. U.S., Inc. to Outer Continental Shelf Enviro. Assessment Progr., Nat. Oceanic and Atmos. Admin., Boulder, Colo. 71 p.

Davis, R.A., Bradstreet, M.S.W., Holdsworth, C., McLaren, M.A., and Richardson, W.J. 1974. Studies of the number and distribution of birds in the central Canadian arctic--1974: a preliminary rept. Unpubl. Rept. by LGL Ltd. to Polar Gas Project. 238 p.

Davis, R.A., Richardson, W.J., Johnson, S.R., and Renaud, W.E. 1978a. Status of the Lancaster Sound narwhal population in 1976. Rep. Int. Whal. Commn. 28: 209-215.

Davis, R.A., Koski, W.R. and Finley, K.J. 1978b. Numbers and distribution of walruses in the central Canadian High Arctic. Unpubl. Rept. by LGL Ltd. for Polar Gas Project, Toronto. 50 p.

Davis, R.A., Finley, K.J. and Richardson, W.J. 1978c. The present status and future management of arctic marine mammals in Canada. Unpubl. Rept. by LGL Ltd. to Science Advisory Board of the Northwest Territories. 222 p.

Dawson, O., 1907. The Currents in Belle Isle Strait, Dept. of Marine and Fisheries, pp. 1-43, Ottawa.

Defant, A., 1961. Physical Oceanography, Vol. 1. Macmillan Co., New York. 729 pp.

Degerbol, M. and Nielsen, N.L. 1930. Biologiske Iagttagelser over og Malinger Hvidhavalen (Delphinaterus leucas (Pall.)) og dens Fostre. (Biological observations and measurements of the beluga and its foetuses.). Meddelelser om Gronland 77: 119-144.

Divoky, G.J. 1976. The pelagic feeding habits of Ivory and Ross' Gulls. Condor 78: 85-90.

Dohler, G., (1966). Tides in Canadian Waters. Canadian Hydrographic Service, 14 pp.

Dunbar, M.J. 1946. On Themisto libellula in Baffin Island coastal waters. J. Fish. Res. Board Can. 6: 319-334.

Dunbar, M.J. 1951. Eastern Arctic Waters. A Bulletin No. 88, Fisheries Research Board of Canada, 130 pp.

Dunbar, M.J. 1957. The determinants of production in northern seas: a study of the biology of Themisto libellula Mandt. Can. J. Zool. 35: 797-819.

Dunbar, M.J. 1968. Ecological development in polar regions. Prentice-Hall, Inc. Englewood Cliffs, N.J. 119 p.

Dunbar, M.J. 1970. On the fishery potential of the sea waters of the Canadian north. Arctic 23: 150-174.

Dunbar, M.J. and Hildebrand, H.H. 1952. Contribution to the study of the fishes of Ungava Bay. J. Fish. Res. Board Can. 9: 83-128.

Dunnet, G.M. and Ollason, J.C. 1978. The estimation of survival rate in the Fulmar, Fulmarus glacialis. J. Anim. Ecol. 47: 507-520.

Duvall, A.J. and Handley, C.O. 1946. Report of wildlife reconnaissance of the eastern Canadian Arctic. Special Report, United States Department of the Interior, Fish and Wildl. Serv., manuscript report. 138 p. (Also Can. Wildl. Serv., Ottawa, Rept. C.W.S. 239. 138 p.).

Ehrenberg, C.G. 1841. Einer Nachtrag zu dem Vortrage uber Verbreitung and Einfluss des mikroscopischen Lebens in Sundund Nord-Amerika. Monatsber. d. Berl. Akad. 1841: 202-207.

Ehrendberg, C.G. 1853. Uber neue Anschauungen des kleinsten nordlichen Polarlebens. Monatsber. d. Berl. Akad. 1853: 522-529.

Ellis, D.V. 1957. Marine infaunal benthos in Arctic North America. Ph.D. Thesis, McGill University, Montreal. 98 p.

Ellis, D.V. 1960. Marine infaunal benthos in Arctic North America. Arctic Inst. N. Amer. Tech. Pap. No. 5. 53 p.

Ellis, D.V. 1962. Observations on the distribution and ecology of some arctic fish. Arctic 15: 179-189.

Evans, P.G.H. and Waterston, G. 1976. The decline of the Thick-billed Murre in Greenland. Polar Record 18: 283-293.

Evans, P.G.H. and Waterston, G. 1978. The decline of the Brunnich's Guillemot in West Greenland. Ibis 120: 131-132.

Falcener, G. Glaciers of Northern Baffin and Bylot Island, N.W.T. Geographical Paper No. 33.

Fay, F.H., Feder, H.M. and Stoker, S.W. 1977. An estimation of the impact of the Pacific Walrus population on its food resources in the Bering Sea. U.S. Marine Mammal Commission Report Nos. MMC-75/06, MMC-74/03. 38 p. NTIS-PB-273-505.

Fenco, 1974. The Northwest Passage, An Environmental Study Related to Offshore operations with Emphasis in Lancaster Sound. A study for Norlands Petroleum Ltd., by the Foundation of Canada Engineering Corporation Ltd.

Finley, K.J. 1976. Studies of the status of marine mammals in the central District of Franklin, N.W.T. June-August, 1975. Unpubl. Rept. by LGL Ltd. to Polar Gas Project. 183 p.

Finley, K.J. 1978. Behaviour and densities of Ringed Seals (Phoca hispida) during haul out in the high Arctic, June 1977. Unpubl. Rept. by LGL Ltd. for Polar Gas Project. 107 p.

Finley, K.J. and Johnston, G. 1977. An investigation of the distribution of marine mammals in the vicinity of Somerset Island with emphasis on Bellot Strait, August-September 1976. Unpubl. Rept. by LGL Ltd. to Polar Gas Project. 71 p.

Fisher, J. 1952. The fulmar. The New Naturalist, Collins, London. 496 p.

Fissel, D.B. and Marko, J.R., 1978. A Surface Current Study of Eastern Parry Channel, N.W.T. Contractor Report Series 78-4, Institute of Ocean Sciences, Patricia Bay, B.C.

Fissel, D.B. and Wilton, G.R., 1978. Subsurface Current Measurements in Eastern Lancaster Sound, N.W.T. - Summer 1977. Contractor Report Series 78-3, Institute of Ocean Sciences, Patricia Bay, B.C., 72 pp.

Fissel, D.B., Lemmon, D.D. and Wilton, G.R., 1978. A Preliminary Report in Physical Oceanographic and Iceberg Movement Studies in Northwestern Baffin Bay. Submitted to Petro-Canada.

Fortier, et al., 1963. Geology of the North - Central Part of the Arctic Archipelago Northwest Territories (Operation Franklin). Geol. Surv. Can. memoir 320.

Foy, M.G. and Hsiao, S.I.C. 1976. Phytoplankton data from the Beaufort Sea, 1973 to 1975. Fish. Res. Board Can. Tech. Rept. No. 617. 44 p.

Freeman, M. (ed.). 1976. Inuit land use and occupancy project. Dept. of Indian and Northern Affairs, Ottawa. 3 vols.

Freuchen, P. 1921. Occurrence and migrations of the walrus near the west coast of Greenland. Danish Society of Natural History, Copenhagen, Scientific Information 72: 237-249.

Freuchen, P. and Salomonsen, F. 1958. The arctic year. G.P. Putnam's Sons, New York. 438 p.

Frost, K.J., Lowry, L.F. and Burns, J.J. 1978. Trophic relationships among ice-inhabiting phocid seals. Appendix I: Offshore demersal fishes and epibenthic invertebrates of the northeastern Chukchi and western Beaufort seas. Unpubl. Rept. by Alaska Dept. of Fish and Game to OCSEAP. 30 p and 80 tables.

Gauthier, J., Bedard, J. and Reed, A. 1976. Overland migration by Common Eiders of the St. Lawrence estuary. Wilson Bull. 88: 333-344.

Godfrey, W.E. 1966. The birds of Canada. Nat. Mus. Can. Bull. 203: 1-428.

Grainger, E.H. 1965. Zooplankton from the Arctic Ocean and adjacent Canadian waters. J. Fish. Res. Board Can. 22: 543-564.

Grainger, E.H. 1971. Biological oceanographic observations in Frobisher Bay. II. Zooplankton data, 1967-1970. Fish. Res. Board Can. Tech. Rept. No. 266. 61 p.

Grant, A.C. 1971. Distributional trends in the recent marine sediments of Northern Baffin Bay. Unpub. Ms., B.I.O. Rept. 65-9.

Green, J.M. and Steele, D.H. 1975. Observations on marine life beneath sea ice, Resolute Bay, N.W.T. Section II: Marine ecology. Proc. Circumpolar Conference on Northern Ecology, Ottawa. pp. 77-86.

Greendale, R.G. and Brousseau-Greendale, C. 1977. Observations of marine mammal migrations at Cape Hay, Bylot Island during the summer of 1976. Dept. of Environ., Fish. and Marine Serv., Res. and Devel. Div. Tech. Rept. 680. 25 p.

Gunn, W.W.H. 1949. Report on wildlife observations, arctic weather station re-supply mission, July 15 to September 7, 1949. MS Rept. to Dominion Wildl. Serv., Dept. of Mines and Resources.

Hainault, R. 1966. Botany of Inugsuin Fiord Area, Baffin Island, N.W.T. In: O.H. Loken et al Field Report North-Central Baffin Island; Geographical Branch 905-18-8.

Hamburg, A., 1884. Hydrogafish Kemisko Iakttagelser under den svensta Expeditionen til Granland 1883. Pih. till k. Sv. Vel - Akad. Itandl., 9, 1-65.

Hanssen-Feyling, Rolf W., 1966. The Cylde Foreland; Field Report, North-Central Baffin Island.

Harrison, D.A., 1964. A Reconnaissance Glacier and Geomorphological Survey of the Duart Lake area, Bruce Mountains, Baffin Island, N.W.T., Geographical Bulletin, No. 22.

Hildebrand, H. 1948. Marine fish of Arctic Canada. M. Sc. Thesis, McGill University, Montreal. 123 p.

Hodgsen, D.A., and Haselton, G., 1974. Reconnaissance Glacial Geology, Northeastern Baffin Island, Geol. Surv. Can. paper 74-20.

Hognestad, P.T. 1968. Observations on polar cod in the Barents Sea. Rapp. P.-v. Reun. Cons. Int. Explor. Mer 158: 126-130.

Hopkins, T.L. 1969. Zooplankton standing crop in the Arctic Basin. Limnol. Oceanogr. 14: 80-85.

Horner, R.A. 1974. History and recent advances in the study of the ice biota. University of Alaska. Inst. Mar. Sci. Unpubl. Manuscript. 26 p.

Horner, R.A. 1977. History and recent advances in the study of ice biota. In: M.J. Dunbar (ed.), Polar Oceans. Arctic Inst. N. Amer. pp. 269-283.

Horner, R.A., Coyle, K.O. and Redburn, D.R. 1974. Ecology of the plankton of Prudhoe Bay, Alaska. Univ. of Alaska Inst. Mar. Sci. Rept. No. R74-2. 78 p.

Horring, R. 1937. Birds collected on the Fifth Thule expedition. Rept. 5th Thule Exped., 1921-24. 2(6): 1-133 plus 1 map, Zoology. Copenhagen.

Hsiao, S.I.C. 1976. Biological productivity of the southern Beaufort Sea: phytoplankton and seaweed studies. Beaufort Sea Tech. Rept. No. 12c. 99 p.

Hyndman, R.D., Clarke, D.B., Hume, H., Johnson, J., Keen, M.J., Park, I. and Pye, G., 1971. Geophysical and Geological Studies in Baffin Bay and the Labrador Sea; Earth Science Symposium on Offshore Eastern Canada; Geol. Surv. Can. paper 71-23.

Ives, J.D., 1962. Indications of Recent Extensive Glacierization in North-Central Baffin Island, N.W.T., Journal of Glaciology, Vol. 4 No. 32.

Ives, J.D. and Andrews, J.T., 1962, Studies in the Physical Geography of North-Central Baffin Island, N.W.T., Geographical Bulletin No. 19.

Jackson, G.D. and Davidson, A. 1975. Bylot Island Map - area District of Franklin, Geol. Surv. Can. paper 74-29.

Jackson, G.D., Davidson, A. and Maryan, W.C., 1975. Geology of the Pond Inlet Map - area, Baffin Island, District of Franklin, Geol. Surv. Can. paper 74-25.

Jansson, A.M. and Kautsky, N. 1977. Quantitative survey of hard-bottom communities in a Baltic archipelago. Eur. Mar. Biol. Symp., 11th, Galway, Ire. 1976. pp. 359-366.

Jensen, A. S. 1935. The Greenland halibut (*Reinhardtius hippoglossoides* (Walb.)): its development and migrations. Kgl. Danske Vidensk. Selsk., Natur. og Mathem. afd., 9, Raekke, VI(4). 32 p.

Jensen, A. S. 1948. Contributions to the ichthyofauna of Greenland, 8-24. Spoila Zoologica Musei Hauniensis IX. 182 p.

Johnson, M.L., Fiscus, C.H., Ostenson, B.T. and Barbour, M.L. 1966. Marine Mammals. *In*: Environment of the Cape Thompson region, Alaska. U.S. Atomic Energy Commission. pp. 887-924.

Johnson, S.R. 1978. Annual report, Beaufort Sea barrier island-lagoon ecological process studies: Avian ecology in Simpson Lagoon, 1977. Unpubl. Rept. by LGL Ltd. U.S., Inc. to Outer Continental Shelf Envir. Assessment Prog., Nat. Oceanic and Atm. Admin., Boulder, Colo. 112 p.

Johnson, S.R., Renaud, W.E., Richardson, W.J., Davis, R.A., Holdsworth, C. and Hollingdale, P.D. 1976a. Aerial surveys of birds in eastern Lancaster Sound, 1976 (Vol. 1) and Appendix A--Distribution Maps (vol. 2). Unpubl. Rept. by LGL Ltd. to Norlands Petroleums ltd. 365 p. and 307 maps.

Johnson, S.R., Renaud, W.E., Davis, R.A. and Richardson, W.J. 1976b. Marine mammals recorded during aerial surveys of birds in eastern Lancaster Sound, 1976. Unpubl. Rept. by LGL Ltd. to Norlands Petroleums Ltd. 180 p.

Kapel, F.O. 1975a. Preliminary notes on the occurrence and exploitation of smaller Cetacea in Greenland. J. Fish. Res. Board Can. 32: 1079-1082.

Kapel, F.O. 1975b. Recent research on seals and seal hunting in Greenland. Rapp. P.-v. Reun. Cons. int. Explor. Mer 169: 462-478.

Karrick, N.L. 1977. Alterations in petroleum resulting from physio-chemical and microbiological factors. In: D.C. Malins (ed.), Effects of Petroleum on Arctic and Subarctic Marine Environments and Organisms. Vol. I. Academic Press Inc. pp. 225-299.

Kemper, B. 1976. Sea birds and related species of the Admiralty Inlet Area. In: B. Kemper (ed.), Environmental baseline studies--1975. Strathcona Sound program. Preliminary Report 1976. Can. Wildl. Serv. Unpubl. Rept. 119 p.

Kii Levich, A.B. (1939). A theoretical treatment of the hydrographical observational material, the Godthaab expedition. Meddelelser om Gronland. V.78, 5 1-148.

Kiliaan, H.P.L. and Stirling, I. 1978. Observations on overwintering walruses in the eastern Canadian High Arctic. J. Mamm. 59: 197-200.

King, T., Cuchlaine, A.M. and Buckley, J.T., 1969. Geomorphological Investigations in West-Central Baffin IslanD, N.W.T., Canada, Arctic and Alpine Research, Vol. 1 No. 2.

King, T., Cuchlaine, A.M. 1969. Glacial Geomorphology and Chronology of Henry Kater Peninsula, East Baffin Island, N.W.T., Arctic and Alpine Research, Vol. 1 No. 3.

King, T., Cuchlaine, A.M. 1969. Moraine types on Henry Kater Peninsula, East Baffin Island, N.W.T. Canada, Arctic and Alpine Research, Vol. 1 No. 4.

Kleinenberg, S.E., Yablokov, A.V., Bel'kovich, B.M. and Tarasevich, M.N. 1964. Beluga, Delphinapterus leucas. Investigation of the species. Akademii Nauk. S.S.S.R., Institute Morfologii Zhivotnykh Im. A.N. Severtsova, Moskva. (Israel Program Sci. Transl. 1969). 376 p.

Kosygin, G.M. 1971. Feeding of the bearded seal *Erignathus barbatus nauticus* (Pallas) in the Bering Sea during the spring-summer period. Izv. Tikhooken. Nauchno-Issled. Inst. Rybn. Khoz. Okeanogr. 75: 144-151. (F.R.R. Transl. Ser. No. 3747, 1976).

Kriss, A.E., Mishustina, I.E., Mitskevich, N. and Zemstova, E.V. 1967. Microbial Population of Oceans and Seas. St. Martin's Press, New York. 287 p.

Krummel, O., 1907. Handbuch der Ozeanographic, Vol. I., 526 pp., Leipzig.

Kupipicka, J. 1973. Granulite Facies Rocks on Northeastern Devon Island, Arctic Archipelago, Geol. Surv. Can. paper 73-8.

Lalli, C.M. 1970. Structure and function of the buccal apparatus of *Clione limacina* (Phipps) with a review of feeding in gymnosomatous pteropods. J. Exp. Mar. Biol. Ecol. 4: 101-118.

Lamothe, P. 1973. Biology of the King Eider (*Somateria spectablilis*) in a freshwater breeding area on Bathurst Island, N.W.T. M.Sc. Thesis, University of Alberta, Edmonton. 125 p.

Lawrie, A. 1950. Field report of a biological reconnaissance of the eastern Canadian Arctic archipelago July-September 1950. Can. Wildl. Serv. Unpubl. Rept. 32 p.

Lear, W.H. 1970. The biology and fishery of the Greenland halibut (*Reinhardtius hippoglossoides* (Walbum)) in the Newfoundland area. M.Sc. Thesis, Memorial University, St. John's, Newfoundland. 132 p.

Lee, R.F. 1974. Lipid composition of the copepod *Calanus hyperboreus* from the Arctic Ocean. Changes with depth and season. Mar. Biol. 26: 313-318.

Lee, R.K.S. 1973. General ecology of the Canadian arctic benthic marine algae. arctic 26: 32-43.

Legendre, V., Hunter, J.G. and McAllister, D.E. 1975. French, English and scientific names of marine fishes of arctic Canada. Natl. Mus. of Can., Syllogeus No. 7. 15 p.

Leim, A.H. and Scott, W.B. 1966. Fishes of the Atlantic coast of Canada. Bull. Fish. Res. Board Can. No. 155. 485 p.

Lemieux, L. 1959. The breeding biology of the Greater Snow Goose on Bylot Island, Northwest Territories. Can. Field-Nat. 73: 117-128.

Lemon, R.R.H. and Blackadar, R.G. 1963. Admiralty Inlet Area, Baffin Island, District of Franklin. Geol. Surv. Can. memoir 328.

Lett, P.F. and Benjaminsen, T. 1977. A stochastic model for the management of the northwestern Atlantic harp seal (Pagophilus groenlandicus) population. J. Fish. Res. Board Can. 34: 1155-1187.

Levy, E.M. 1977. The geographic distribution of tar in the North Atlantic. In: Petroleum Hydrocarbons in the Marine Environment. I.C.E.S. Workshop, Aberdeen. Sept. 9-12, 1975. Rapp. P.-v. Reun. Cons. int. Explor. Mer, 1971: 55-60.

Loken, Olav H. 1965. Postglacial Emergence at the South End of Inugsuin Fiord, Baffin Island, N.W.T., Geographical Bulletin, Vol. 7 No. 314.

Loken, Olav H. 1966. Science on Baffin Island - Field Research in Physical Geography, Can. Geog. Jour. Vol. 72 No. 2.

Low, A.P. 1906. The cruise of the Neptune. Ottawa.

Lowry, L.F., Frost, K.J. and Burns, J.J. 1978. Trophic relationships among ice-inhabiting phocid seals. OCSEAP Annual Rept., R.U. 232. 68 p.

Lubbock, B. 1937. The arctic whalers. Brown, Son and Ferguson, Ltd., Glasgow, Scotland. 480 p.

Lubinsky, I. 1972. Marine bivalve molluscs of the Canadian arctic. Ph.D. Thesis, McGill University, Montreal, 318 p.

Lubinsky, I. 1976. Thyrasira dunbari n.sp. (Bivalvia: Thyrasiridae) from the Canadian arctic archipelago. J. Fish. Res. Board Can. 33: 1667-1670.

Macdonald, M.A. 1977. An analysis of recoveries of British-ringed fulmars. Bird Study 24: 208-214.

MacDonald, S.D. 1976. Phantoms of the polar pack ice. Audubon 78: 2-19.

Mansfield, A.W. 1958. The biology of the Atlantic walrus Odobenus rosmarus rosmarus (Linnaeus) in the eastern Canadian Arctic. Fish. Res. Board Can., MS Rept. Ser. (Biol.) No. 653. 145 p.

Mansfield, A.W. 1967. Seals of arctic and eastern Canada (2nd ed., revised). Fish. Res. Board Can. Bull. 137: 1-35.

Mansfield, A.W. 1971. Occurrence of the Bowhead or Greenland Right Whale (Balaena mysticetus) in Canadian Arctic Waters. J. Fish. Res. Board Can. 28: 1873-1875.

Mansfield, A.W. 1973. The Atlantic walrus Odobenus rosmarus in Canada and Greenland. Int. Union Cons. Nat. Suppl. paper 39: 69-79.

Mansfield, A.W., Smith, T.G. and Beck, B. 1975. The narwhal, Monodon monoceros, in eastern Canadian waters. J. Fish. Res. Board Can. 32: 1041-1046.

Markham, W.E. 1976. Ice Chematology of Lancaster Sound (unpublished memorandum).

Marko, J.R. 1977. A Satellite-based Study of Sea-Ice Dynamics in the Central Canadian Arctic Archipelago. Contractor Report Series, Institute of Ocean Sciences, Patricia Bay, B.C.

Marko, J.R. 1978. A Satellite Imagery Study of Eastern Parry Channel Contractor Report Series 78-5, Institute of Ocean Sciences, Patricia Bay, B.C.

Marquette, W.M. 1977. The 1976 catch of bowhead whales (Balaena mysticetus) by Alaskan eskimos, with a review of the fishery, 1973-1976, and a biological summary of the species. Northwest and Alaska Fisheries Center Processed Rept., Nat. Marine Fisheries Serv., Seattle. 96 p.

Marshall, K.E. 1977. A bibliography of the Arctic char, Salvelinus alpinus (L.) complex to 1976. Environment Canada, Fish. and Mar. Serv., Tech. Rept. No. 621. 49 p.

Marshall, S.M. and Orr, A.P. 1962. Food and feeding in copepods. Rapp. P.-v. Reun. Cons. per. int. Explor. Mer 153: 92-98.

Mary-Rousseliere, G. 1959. Shark fishing at Pond Inlet. Eskimo (publ. by the Oblate Fathers of the Hudson Bay Vicariate, Churchill, Manitoba) 52: 10-13.

McAllister, D.E. 1975. Ecology of marine fishes of arctic Canada. Section II. Marine ecology. Proceedings of the Circumpolar Conference on Northern Ecology, Ottawa. pp. 49-65.

McGowen, W.E., Saner, W.A. and Hufford, G.L. 1974. Tar ball sampling in the Western North Atlantic. In: Marine Pollution Monitoring, NBS. Spec. Pub. 409: 83-4. Proc. Symp. and Workshop held at the Nat. Bur. Standards, Gaithersburg, Md., May 13-17, 1974.

McLaren, I.A. 1958. The biology of the ringed seal (Phoca hispida Schreber) in the eastern Canadian arctic. Fish. Res. Board Can. Bull. 118. 97 p.

McLaren, M.A. and Renaud, W.E. 1977. Numbers and distribution of birds on eastern Melville Island, July-August 1977. Unpubl. Rept. by LGL ltd. to Petro-Canada. 139 p.

McVay, S. 1973. Stalking the arctic whale. American Scientist 61: 24-37.

Mead, C.J. 1974. The results of ringing auks in Britain and Ireland. Bird Study 21: 45-86.

Mecking, L. 1906. Die Eisdrift aws dem Bereich der Baffin Bay beherst van Strom and Wetter Veruffentlschungen des Instituts fer Meereskunde. Heft 7, pp. 1-132.

Mecking, L. 1907. Die Treibeischeinungen bei Neufundland in ihrer Abhangigkeit von Witlerunggsuer haltnissen, Annalen d'Hydrogrg aphie und Maritimen Meterologie Vol. 35, pp. 348-355 and 296-409.

Miller, G.H., Andrew, J.T. and Short, S.K. 1977. The Lost interglacial - glacial cycle, Cycle fineland Baffin Island, N.W.T.: Stratigraphy, biostratigrophy and chronology, Canadian Journal of Earth Sciences, Vol. 14 No. 12.

Miller, R.S. 1955. A survey of the mammals of Bylot Island, Northwest Territories. Arctic 8: 167-176.

Milne, A.R. and Smiley, B.D. 1978. Offshore Drilling in Lancaster Sound: Possible Environmental Hazards, Institute of Ocean Sciences, Patricia Bay, B.C.

Mitchell, E.D. 1973. The status of the world's whales. Nature Can. 2(4): 9-25.

Mitchell, E.D. 1975. Trophic relationships and competition for food in northwest Atlantic whales. Can. Soc. Zool. Proc. Ann. Meeting: 123-133.

Mohammed, A.A. and Grainger, E.H. 1974. Zooplankton data from the Canadian arctic archipelago, 1962. Fish. Res. Board Can. Tech. Rept. No. 460. 135 p.

Moore, J.W. and Moore, I.A. 1974. Food and growth of Arctic char, <u>Salvelinus alpinus</u> (L.), in the Cumberland Sound area of Baffin Island. J. Fish. Biol. 6: 79-92.

Mowat, F. 1960. Ordeal by Ice 422 pp. McClelland and Stewart Ltd., Toronto.

Mowat, F. (1965). Westviking, McClelland and Stewart, Toronto. 492 pp.

Muench, R.D. (1971). The physical oceanography of the northern Baffin Bay region. The Baffin Bay - Northwater Project, Scientific Report No. 1, Arctic Institute of N. America. 150 pp.

Mulkins-Phillips, G.H. and Stewart, J.E. 1974. Distribution of hydrocarbon-utilizing bacteria in northwestern Atlantic waters and coastal sediments. Can. J. Microbial. 20: 955-962.

Mullin, M.M. 1963. Some factors affecting the feeding of marine copepods of the genus <u>Calanus</u>. Limnol. Oceanogr. 8: 239-250.

Murray, J.E. 1968. The drift deterioration and distribution of icebergs in the North Atlantic Ocean, Ice Seminar, Petroleum Society of CIM, Calgary.

Nettleship, D.N. 1974. Seabird colonies and distributions around Devon Island and vicinity. Arctic 27: 95-103.

Nettleship, D.N. 1977. Studies of seabirds at Prince Leopold Island and vicinity, Northwest Territories. Preliminary report of biological investigations in 1975. Can. Wildl. Serv. Prog. Notes No. 73. 11 p.

Nettleship, D.N. and Gaston, A.J. 1978. Patterns of pelagic distribution of seabirds in western Lancaster Sound and Barrow Strait, N.W.T. Canadian Wildlife Service Occ. Paper No. 39: 1-40.

Nichols, F.H. 1970. Benthic polychaete assemblages and their relationships to the sediment in Port Madison, Washington. Mar. Biol. 6: 48-57.

Nielsen, J.W. 1909a. Forelobig Meddelelse om Undersolgelser over Vestgronlands Hydrografi, Foretagne under "Tjalfe" - Expedition 1908 Beretn. og kundgorelser vedrorende kolunierne: Gronl. pp. 24-27.

Nielsen, J.W. 1909b. Forelobig Meddelelseom de fra Briggen "Tjalfe" foretagne hydrografiske Undersogelseune i Sommerem. Beretn. og kundgorelser vedrorende kolonierne i Gronl., (5) pp. 106-110.

Nielsen, J.W. 1928. Waters round Greenland. Greenland 1, pp. 185-230, C.A. Reitzel, Copenhagen.

Nielsen, J.G. and Jensen, J.M. 1967. Revision of the Arctic cod genus, Arctogadus (Pisces, Gadidae). Meddelelser om Gronland 184: 1-29.

Nikolskii, G.V. 1961. Special ichthyology. Published for the National Science Foundation and Smithsonian Inst. by the Israel Program for Scientific Transl., Jerusalem, 1961. 538 p.

Norlands Ltd. 1978. Environmental Impact Statement for exploratory drilling in the Lancaster Sound region. Rept. by Norlands Petroleums Ltd., Calgary, 683 p.

Ockelmann, W.K. 1958. The zoology of East Greenland; Marine Lamellibranchiata. Meddelelser om Gronland 122: 1-256.

Ollason, J.C. and Dunnet, G.M. 1978. Age, experience and other factors affecting the breeding success of the fulmar, Fulmarus glacialis, in Orkney. J. Anim. Ecol. 47: 961-976.

Palmer, R.S. 1976a. Handbook of North American birds. Vol. 2: Waterfowl (Part 1). Yale University Press, New Haven and London. 521 p.

Palmer, R.S. 1972b. Handbook of North American birds. Vol. 3: Waterfowl (Part 2). Yale University Press, New Haven and London. 560 p.

Past, V.K. 1952. Notes on the Geology of Parts of Ellesmere and Devon Islands, Northwest Territories, Geol. Serv. Can. paper 52-32.

Pelletier, B.R., Ross, D.I., Keen, C.E., and Keen, M.J. 1974. Geology and Geophysics of Baffin Bay. Offshore Geol. of E. Canada, G.S.C. paper 74-30, Vol. 2: 247-258.

Perry, R.B. 1961. A study of the marine sediments of the Canadian Eastern Arctic Archipelago. Fish. Res. Board Canada, Ms. Rept., No. 89.

Pilot of Arctic Canada, 1970. Vol. 5, 2nd Edition, Canadian Hydrographic Service, Dept. of Fisheries and Environment, Ottawa.

Ponomarenko, V.P. 1967. Feeding of larvae and fry of the Arctic cod, _Boreogadus saida_ Lepechin, in the Barents and Kara Seas. Polyarn. Nauchno-Issled. Praektynyi Inst. Morsk. Rybn. Khov. Okeanogr., Materialy Rybokhoz. Issled. Severnago Basseina. 10: 20-27. (Transl. from Russian by U.S. Bur. Sport Fish. Wildl., 1968).

Ponomarenko, V.P. 1968. Some data on the distribution and migrations of polar cod in the seas of the Soviet Arctic. Rapp. P.-v. Reun. Int. Explor. Mer 158: 131-133.

Poulet, S.A. 1976. Feeding of _Pseudocalanus minutus_ on living and non-living particles. Mar. Biol. 34: 117-125.

Preston, W.C. 1968. Breeding ecology and social behaviour of the Black Guillemot, _Cepphus grylle_. Unpubl. Ph.D. Thesis. University of Michigan, Ann Arbor. 138 p.

Rass, T.S. 1968. Spawning and development of polar cod. Rapp. P.-v. Reun. Cons. Int. Explor. Mer 158: 135-137.

Raymont, J.E.G. 1963. Plankton and productivity in the oceans. Pergamon Press, New York. 660 p.

Renewable Resources Consulting Services Ltd. (R.R.C.S.). 1977. Aerial surveys of marine mammals of Lancaster Sound, 1975-1976. Unpubl. Rept. to Norlands Petroleums Ltd. 110 p.

Robe, R.Q. 1975. The Physical Properties of Icebergs: height to Draft Ratios of Icebergs, Department of Transportation, Coast Guard Bulletin No. 61, pp. 70-77.

Rodman, H. 1890. Reports on Ice and Ice Movements in the North Atlantic Ocean, U.S. Navy Hydrographic Office, No. 93, 26 pp.

Ross, D.I., Keen, C.E., Banett, D.L. and Manchester, K.S. 1971. Geophysical studies on the structure of Baffin Island, Earth Science Symposium on Offshore Eastern Canada, Geol. Surv. Can. paper 71-23.

Ross, D.I. and Falconer, R.K.H. 1974. Geological Studies of Baffin Bay, Davis Strait and Adjacent Continental Margins, Geol. Serv. Can. paper 75-1, part A.

Russell, R.H. 1975. The food habits of polar bears of James Bay and southwest Hudson Bay in summer and autumn. Arctic 28: 117-129.

Salomonsen, F. 1950. The birds of Greenland. Parts I and II. Musksgaard, Copenhagen. 347 p.

Salomonsen, F. 1967. Fuglene pa Gronland. Rhodos, Copenhagen. 340 p.

Salomonsen, F. 1968. The moult migration. Wildfowl 19: 5-24.

Salomonsen, F. 1970. Birds useful to man in Greenland. <u>In</u>: W.A. Fuller and P.G. Kevan (eds.), Productivity and conservation in northern circumpolar lands. International Union for Conservation of Nature and Natural Resources, Morges, Switzerland. 344 p.

Salomonsen, F. 1972. Zoogeographical and ecological problems in Arctic birds. Proc. XVth Int. Ornithol. Congr. pp. 25-77.

Sanders, H.L. 1960. Benthic studies in Buzzards Bay III. The structure of the soft bottom community. Limnol. Oceanogr. 5: 138-153.

Sanford, R.C. and Harris, S.W. 1967. Feeding behavior and food-consumption rates of a captive California murre. Condor 69: 298-302.

Schweinsburg, R.E., Stirling, I., Oosenburg, S. and Kiliaan, H. 1977. A status report on polar bear studies in Lancaster Sound. Northwest Territories Fish and Wildl. Serv. Rept. to Norlands Petroleums Ltd. Part I: 56 p.; Part II: 27 p.

Scott, W.B. and Crossman, E.J. 1973. Freshwater fishes of Canada. Fish. Res. Board Can. Bull. No. 184. 966 p.

Sekerak, A.D., Thomson, D., Bain, H. and Acreman, J. 1976a. Summer surveys of the marine ecology of Creswell Bay, Somerset Island, and Assistance Bay, Cornwallis Island, N.W.T. 1975. Unpubl. Rept. by LGL Ltd. to Polar Gas Project. 215 p.

Sekerak, A.D., Buchanan, R.A., Griffiths, W.B. and Foy, M.G. 1976b. Biological oceanographic studies in Lancaster Sound, 1976. Unpubl. Rept. by LGL Ltd. to Norlands Petroleums Ltd. 169 p.

Sergeant, D.E. 1965. Migrations of harp seals *Pagophilus groenlandicus* (Erxleben) in the northwest Atlantic. J. Fish. Res. Board Can. 22: 433-464.

Sergeant, D.E. 1973a. Biology of white whales (*Delphinapterus leucas*) in western Hudson Bay. J. Fish. Res. Board Can. 30: 1065-1090.

Sergeant, D.E. 1973b. Feeding, growth and productivity of northwest Atlantic harp seals (*Pagophilus groenlandicus*). J. Fish. Res. Board Can. 30: 17-29.

Sergeant, D.E. 1976a. History and present status of populations of harp and hooded seals. Biol. Conserv. 10: 95-118.

Sergeant, D.E. 1976b. The relationship between harp seals and fish populations. ICNAF Res. Doc. 76/X/125 Serial No. 4011. 19 p.

Sergeant, D.E. and Brodie, P.F. 1975. Identity, abundance and present status of populations of white whales, *Delphinapterus leucas*, in North America. J. Fish. Res. Board Can. 32: 1047-1054.

Sergeant, D.E. and Hay, K. 1977. Observations on the distribution and abundance of sea mammals, particularly the narwhal, in northern Baffin Island. Arctic Islands Pipeline Prgram Interim Rept. - Marine Wildlife. 7 p.

Shoemaker, C.R. 1955. Amphipoda collected at the Arctic Laboratory, Office of Naval Research, Point Barrow, Alaska, by G.E. MacGinitie. Smith. Misc. Coll. 128. 78 p.

Shortt, T.M. and Peters, H.S. 1942. Some recent bird records from Canada's eastern arctic. Can. J. Res. 20: 338-348.

Sieburth, J. McN. 1976. Bacterial substrates and productivity in marine ecosystems. Ann. Rev. Ecol. Syst. 7: 259-285.

Smith, E.H. 1925. International Ice Patrol, The Meteorological Magazine, The Meteorological Committee, Air Ministry, Vol. 60, No. 718.

Smith, E.H. 1931. The Marine Expedition to Davis Strait and Baffin Bay, Arctic ice with special reference to its distribution in the North Atlantic Ocean. U.S. Treasury Dept., Coast Guard Bull. 19 part 3, pp. 1-121.

Smith, E.H., Soule, F.M. and Mosby, O. 1937. The "Marion" and "General Greene" Expeditions to Davis Strait and Labrador Sea. Scientific Results, Part 2, Physical Oceanography. U.S. Gov. Printing Office, Wash. D.C. 259 pp.

Smith, T.G. 1973. Population dynamics of the ringed seal in the Canadian eastern Arctic. Fish. Res. Board Can. Bull. No. 181. 55 p.

Smith, T.G. 1976. Predation of ringed seal pups (*Phoca hispida*) by the arctic fox (*Alopex lagopus*). Can. J. Zool. 54: 1610-1616.

Smith, T.G. and Stirling, I. 1975. The breeding habitat of the ringed seal (*Phoca hispida*). The birth lair and associated structures. Can. J. Zool. 53: 1297-1305.

Synder, L.L. 1957. Arctic birds of Canada. University Toronto Press, Toronto. 310 p.

Squires, H.J. 1967. Decapod Crustacea from Calanus collections in Hudson Bay in 1953, 1954 and 1958-61. J. Fish. Res. Board Can. 24: 1873-1903.

Steele, D.H. 1961. Studies in the marine Amphipoda of eastern and northeastern Canada. Ph.D. Thesis, McGill University, Montreal. 350 p.

Steele, D.H. and Steele, V.J. 1974. The biology of Gammarus (Crustacea, Amphipoda) in the north-western Atlantic. VIII. Geographic distribution of the northern species. Can. J. Zool. 52: 1115-1120.

Steele, V.J. and Steele, D.H. 1970. The biology of Gammarus (Crustacea, Amphipoda) in the north-western Atlantic. II. Gammarus setosus Dementieva. Can. J. Zool. 48: 659-671.

Stephensen, K. 1942. The amphipods of North Norway and Spitzbergen with adjacent waters. Tromso Mus. Skrift. 3. 526 p.

Stepney, P.H.R. and Wooley, R.L. 1975. Survey of marine mammals of Lancaster Sound, October 1975. Unpubl. Rept. by Renewable Resources Consulting Serv. Ltd. to Norlands Petroleums Ltd., 55 p.

Stirling, I. 1974. Midsummer observations on the behavior of wild polar bears (Ursus maritimus). Can. J. Zool. 52: 1191-1198.

Stirling, I. and Archibald, W.R. 1977. Aspects of predation of seals by polar bears. J. Fish. Res. Board Can. 34: 1126-1129.

Stirling, I., Archibald, W.R. and DeMaster D. 1977. Distribution and abundance of seals in the eastern Beaufort Sea. J. Fish. Res. Board Can. 34: 976-988.

Steenstrup, K.J.V. 1893: Bidragtil Kjendskab til Braeerne og Brae Isen i Nord Gronland, Meddelelser om Gronland, Vol. 4, pp. 71-112.

Surficial Geology and Geomorphology Simpson Peninsula 1975 Geol. Serv. Can. open file 285.

Sverdrup, H.U., Johnson, M.W. and Fleming R.H. 1942. The oceans. Their physics, chemistry and general biology. Prentice-Hall Inc., New Jersey. 1087 p.

Thomson, D., Woods, S. and Acreman, J. 1975. Marine ecology survey in the central portion of the Canadian Arctic Islands, 1974. Unpubl. Rept. by McGill University to Polar Gas Project. 77 p.

Thorson, G. 1936. The larval development, growth and metabolism of Arctic marine bottom invertebrates compared with those of other areas. Meddelelser om Gronland 100: 1-155.

Thorson, G. 1957. Bottom communities. In: J. Hedgpeth (ed.), Treatise on marine ecology and paleoecology. Vol. 1, Ecology. Geol. Soc. Amer. Mem. 67: 461-534.

Thorsteinsson, R. and Tozer, E.T. 1960. Summary Account of Structural History of the Canadian Arctic Archipelago since Precambrian Time, Geol. Serv. Can. paper 60-7.

Trettin, H.P. 1969. Lower Palaeozoic Sediments of Northwestern Baffin Island, District of Franklin, Geol. Serv. Can. Bulletin 157.

Treude, E. 1977. Pond Inlet, northern Baffin Island: structure of an Eskimo resource area. Polar Geog. 1: 95-122.

Tuck, L. 1957. Wildlife investigations in the Cape Hay region, Lancaster Sound. Can. Wildl. Unpubl. Rept. 39 p.

Tuck, L.M. 1960. The murres--their distribution, populations and biology. Can. Wildl. Serv., Monograph No. 1. 260 p.

Tuck, L.M. 1971. The occurrence of Greenland and European birds in Newfoundland. Bird-Banding 42: 184-209.

Tuck, L.M. and Lemieux, L. 1959. The avifauna of Bylot Island. Dansk Orn. Foren. Tidsskr. 53: 137-154.

Tull, C.E., Germain, P. and May, A.W. 1972. Mortality of Thick-billed Murres in west Greenland salmon fishery. Nature 237: 42-44.

Uspenski, S.M. 1958. The bird bazaars of Navaya Zemlya. USSR Acad. Sci., Moscow (English transl.: Can. Wildl. Serv., Transl. of Russian Game Repts., No. 4). 159 p.

Vibe, C. 1950. The marine mammals and the marine fauna in the Thule district (northwest Greenland) with observations on ice conditions in 1939-1941. Meddelelser om Gronland 150: 1-115.

Vibe, C. 1967. Arctic animals in relation to climatic fluctuations. Meddelelser om Gronland 170: 1-227.

Walsh, J. 1977. Moratorium for the bowhead: eskimo whaling on ice? Science 197: 847-850.

Walters, V. 1955. Fishes of western arctic America and eastern arctic Siberia. Bull. Amer. Mus. Nat. Hist. 106: 255-368.

Wandel, C.F. 1891. Om de hydrogryphisko Forhold: Davis - Straedet Medel om Gronl., 7, 57-1B.

Webb, R. 1976. Sea mammal surveys in Baffin Bay and Davis Strait, September, 1976. Unpubl. Rept. by R. Webb Environmental Serv. Ltd., Richmond, B.C. for Shell Canada. 60 p.

Weeks, L. 1928. Cumberland Sound Area, Baffin Island, Geol. Serv. Can. Sumamry Report.

Welch, H.E. and Kalff, J. 1975. Marine metabolisms at Resolute Bay, Northwest Territories. Section II: Marine ecology. Proc. Circumpolar Conference on Northern Ecology, Ottawa. pp. 67-75.

Wilce, R.T. 1973. Observations on the attached algae of the moderately exposed rocky coast in high latitudes. Arctic Inst. N. Amer., Office and Naval Research Rept. No. 353A3-4. 59 p.

Wing, B.L. 1976. Ecology of *Parathemisto libellula* and *P. pacifica* (Amphipoda: Hyperiidea) in Alaskan coastal waters. Northwest Fish. Center Auke Bay Fish. Laboratory Processed Rept. 266 p.

Wynne-Edwards, V.C. 1952. The fulmars of Cape Searle. Arctic 5: 105-117.

Zenkevitch, L. 1963. Biology of the seas of the U.S.S.R. Interscience, London. 955 p.

5.0 ENVIRONMENTAL IMPACTS AND MITIGATION MEASURES

5.1 THE BASIS FOR IMPACT PREDICTION

The subject of evaluation of impacts resulting from industrial activities has received considerable attention in the literature. Norlands Petroleums Ltd. (1978) noted that the definition used for environmental impacts in the guidelines for preparation of an environmental impact statement for Eastern Arctic offshore exploratory drilling was rather vague, depending on subjective interpretations of key terms. Imperial Oil *et al*.(1978) defined an "impact" as "a cause - effect relationship that can be identified or predicted between any facet of the proposed exploratory drilling operation and any flora or fauna in the surrounding environment." Norlands Petroleums Ltd. (1978), on the other hand, believed that a process of definition of impacts from which matrices are constructed was unduly simplistic. Instead, operational descriptions of the magnitude of the impacts were used.

Kates (1977) commented that it is first necessary to identify the hazards and then estimate the risks that arrive from them. The latter process, he felt, is largely subjective "Its methods are methods of knowing: revelation, intuition and extrapolation from experience." As such, scientific approaches rest primarily on extrapolation from known events or from similar situations. It is for this reason that so much effort has been expended on refining the methods of extrapolation in recent years, by clarifying probability estimates through development of mathematical approaches, developing systems models, or in the construction of "most credible" scenarios. However, as Kates points out, such analyses are limited by the amount and degree of experience "and extrapolative methods, no matter how ingenious, can only enlarge but not escape such containment." The business of peering into the future has always been a risky proposition. The prediction of impacts, therefore, may take on ideological overtones wherever "the perception of hazard is high, the facts of risk are ambiguous, (and) the methods of analysis are limited and still in development. It is not surprising, then, that hope, fear, and faith enter the risk assessment process as overriding views or assumptions that in archetypal expression border on ideology." (Kates, 1977).

The problem of comparing impacts and then choosing an alternative has resulted in the development of quantitative methods of assessment which allow for direct comparisons of the anticipated impacts. Sondheim (1978) and others have proposed ratio and ordinal rating schemes which set out specific criteria for making the assessment. Such methodologies have the drawback of implicitly assuming a negligible degree of synergistic or antagonistic effects between the various aspects of the scheme. As a result of these and other objec-

tions Sondheim (1978) concluded that "an organization employing any assessment methodology should use the process less as an ultimate decision algorithm than as a guideline." This viewpoint is underlined by the detailed risk index developed and used by Fisheries and Environment Canada (1978) in assessing potential Pacific coast oil ports. Not only were risk values not considered to be numerically comparable to other similar studies, the report itself was considered to assess only the relative risks from oil spills in shipments to 11 potential port terminals. Thus, the utility of employing numerical assessments must be questioned. In the elaborate marine study noted above the authors cautioned that "a port/route identified as being "least risky" in this analysis could, on comprehensive and detailed study, be found completely unacceptable .... due to specific liabilities, inadequate benefits or the negative impacts of non-marine factors. The converse might also be true." Such approaches do, however, assist in the identification of highly-susceptible areas or organisms, but the problems in discriminating between areas which have relatively similar rankings remain unresolved by such analyses.

Other statistical approaches have involved the use of Poisson or gamma distributions in the correlation of reported oil spill volumes and frequencies. Future spill volumes and numbers are then calculated from estimated exposure values and trends in spill accidents may be evaluated (Mackay and Wilks, 1978). Once again, however, such estimations are of limited utility when applied to specific, frontier areas from which few data are available.

Alternatively it has been suggested that weightings of impact predictions be based upon public hearings before advisory boards (Trost, 1976). However, Haefeli (1973) argued that such methods do not necessarily reflect the ideals of representative government and should therefore be reconsidered before being widely used.

Bisset (1978) considered that all the methodologies for the quantification and aggregation of impacts have serious disadvantages particularly because "they mask contentious items in an assessment thereby avoiding conflict between those in favour of a proposal and those against." He concluded that an open discussion of impacts is not necessarily aided by such techniques because such methods could be used to control public debate about proposals. Further, attempts to quantify impacts for decision-makers may be misleading because many impacts are not easily quantified (they require judgemental opinions or extrapolation to problematic, hypothetical scenarios) and attempts to do so may distort the true situation because the aggregation of impacts can only be

attempted after a method of weighting impacts has been evolved.

Bisset (1978) concluded that should a decision-maker rely solely on quantitative methods of assessment "the decision would be made for him, not by him. In effect, he would be presented with a fait accompli. Thus, these methods may take the responsibility for decisions out of the decision-makers hands." Although conceding that it places heavy demands upon decision-makers Bisset (1978) recommended that development proposals be openly discussed "based on disaggregated information which has not previously been evaluated by groups of experts or other sections of society" because that method involves fewer assumptions and concealed value judgements than does wholly quantitative assessments.

If such open discussions are, indeed, used as the basis for environmental management decisions the conflicting concerns will have to be weighted. Paproski (1977) suggested that indigenous people provide a valuable source of information about the potential impact of the proposal and that "their views should be actively sought and given appropriate consideration as an important component of a balanced evaluation of divergent concerns and contentions."

In consideration of these, and other studies, no quantification of impacts has been attempted herein. Instead, fundamental concerns are identified and rational assessments about the potential disruptions from "most credible" impact scenarios are discussed by presenting all the data used in reaching any conclusions. It is not suggested that the analyses presented here are definitive. However, an even-handed approach has been attempted so as to facilitate discussions. Major, significant concerns are presented so as to be readily identifiable in the decision-making process. Organisms and local or regional areas of special concern are highlighted so as to facilitate considerations in contingency planning or in evolving operating terms and conditions.

It is acknowledged that assessments will contain the subjective value-judgements of the personnel involved in the preparation of any environmental statements. It is intended that the scientific literature and assessments of the region will be presented so that decision-makers will be able to use the data in reaching well-informed judgements regarding the application.

5.2 THE EFFECT FROM ROUTINE DRILLING OPERATIONS

5.2.1 Drilling Fluids

The major emissions to water from offshore, exploratory drilling arise from the drilling process (drilling fluids and cuttings), the deck operations (deck drainage and washings) and domestic sources (washwater and sanitary wastes). The latter two are considered to be minor sources as compared with the former (Frazier *et al*., 1977).

While cycling systems, such as compressor drains, cooling and heating circuit discharges, also may add to the total effluent cycle they are not considered to be of any significance. The drilling fluids and cuttings from the drilling process are the primary effluent and have been the focus for considerable attention in both Canada (Baker, 1978) and the United States (Frazier *et al*., 1977). It is estimated that over the past 40 years such discharges have been made from over 20,000 offshore wells (Ray, 1978).

For the exploratory drilling program a maximum of four structures are to be tested each with one test well (Table 5-1). The theoretical, minimum times of active (mud-producing) drilling range from 27 to 41 days. If there is a generous contingency time allowance of 50% for environmental or operational problems the times for active drilling which is producing drilling mud range from 41 to 62 days. These estimates yield a range totalling from 134 to 203 drilling mud-producing days (Table 5-1). (This does not include casing or well testing, but *only* active drilling (mud producing) times.

Drilling fluids form a vital component of the drilling process and prevent blowouts by counterbalancing formation pressures, by providing for controls in the borehole wall and by acting as a medium for lubrication and transport of well cuttings. The amount of time that drilling fluids are circulated is determined by the drilling program itself which may vary from 10 days or less to more than 21 days for each completion of the wells. The total number of offshore wells which usually are completed for each development ranges from less than 10 to more than 30 (Frazier *et al*., 1977). Therefore, a maximum estimate of drilling fluid emissions would be 30 wells per development structure with each drilling well extending to somewhat more than 30 drilling-days, for a total of 900 drilling-emission days. Obviously, in high Arctic offshore regions the total emission figure would be spread over a period of many years should drilling proceed. It is exceedingly doubtful that 30 wells would be drilled per structure in Baffin Bay, strictly on the

Table 5-1.

Proposed Baffin Bay Drilling Program

	GEOLOGICAL STRUCTURE			
	BYAM MARTIN	BYLOT	PHILPOTTS	JAMESON
Water depth (m)	840	600	380	850
Drilling depth (m)	2380	1520	2650	2990
Drill time to 240 m (limit or 20" casing)	19days	16days	13days	19days
Drill time to depth*	16days	11days	18days	22days
Drilling days (Theoretical Minimum) (Total 134 days)	35	27	31	41
+50% Contingency (Total 203 days)	(53)	(41)	(47)	(62)

* Frazier et al. (1977) note that in U.S. offshore wells the time involved in the use of drilling mud has ranged from less than 10 days to more than 3 weeks per well completion.

basis of cost, and therefore, the figure of 900 drilling-emission days must be considered as being very much more than could reasonably be expected over even a 10 year period. Such a maximum figure would certainly include exploration, delineation and production drilling.

Frazier et al.(1977) found that for a typical off-shore drilling depth of 10,000 feet (3048 m) about 7,000 barrels (1,113 m^3) (Barrels: 1 bbl=42 US gal. = 35 Imp. gal. = 0.159m^3) of drilling mud containing about 258 tons of commercial components are required and well cuttings can amount to more than 1,700 barrels or about 700 tons of material. For the proposed Baffin Bay exploratory drilling program an estimated total of 31,300 feet (9540 m) are projected to be drilled for the four structures over a minimum time period of 3 years. Therefore, a total use of 21,910 bbls (3484 m^3) of mud containing 801 tonnes of commercial components producing 854 m^3 (2226 tonnes) of cutting could be predicted for the four exploratory wells. Using the previous estimated minimum and maximum drilling times of 134 and 203 days, respectively, one can estimate mud use and cuttings produced as shown in Table 5-2.

In summary, over the anticipated 3 year exploratory drilling span one would predict a need to dispose of a total tonnage of 801 tonnes of mud and 2226 tonnes of cuttings (27,281 bbls or 4,338 m^3) which would be disposed of at a rate of from 15 - 23 tonnes/day (135 - 204 bbls/day). (Refer to Table 5-5: The difficulty in estimating mud usage is illustrated by use of independent methods of calculations. Using the figures in Table 5-5 one derives a calculated mud usage by drilling a total of 9540 m as 1042 tonnes, about 30% more than the 801 tonnes derived above). (See below).

The range of calculated figures serve to indicate that even at the maximum calculated loadings the enormous volume of water in Baffin Bay, into which the mud or cuttings could be disposed, would quickly render the fluids so dilute that they would not present a significant hazard to marine populations of biota.

5.2.1.1. Drilling Fluid Composition and Toxicology

Drilling muds may be generally divided into two broad categories as water-based and oil-based. The water-based muds are made up of fine clays (bentonite or attapulgite) and various other components which are used to promote control lubrication of density properties, or emulsification and prevent corrosion or pH fluctuations. In the U.S. offshore area the water-based muds are usually eventually returned to the ocean.

Table 5-2.

Total Calculated Drilling Mud Used in the Proposed Baffin Bay Drilling Program.

Drilling Times	Mud Used		Cuttings Produced		Total	
	Tonnes	m^3	Tonnes	m^3	Tonnes	m^3
(estimated Total useage)	821	3484	2226	879	3047	4465
	Tonnes/ day	m^3/ day	Tonnes/ day	m^3/ day	Tonnes/ day	m^3/ day
Minimum (134 days)	6.1	27	16.6	6.6	23	33
Maximum (203 days)	4.1	17.7	11	4.4	15	22

The major pollutants from offshore drilling effluents have been considered to be oils and greases, however, concerns have also been raised over specified chemical components. In exploratory drilling only water-based muds are used.

The drilling fluid usually forms a closed system with the cuttings and mud filtered through mud solids separators. The mud is routed through containers while the cuttings are usually disposed overboard. The mud is discharged infrequently and during exploratory drilling it is common practise to discharge all the mud at the completion of the drilling process (Ray, 1978). Specifically, typical compositions of gelled seawater and lignosulfonate muds are shown in Table 5-3. As noted, on a dry weight basis chromium forms about 3% of the mud. The barite ($BaSO_4$), which is by far the principal component of the mud, exerts control over the well increasing mud weight in the drilling column. Other mud activities, their use and normal concentration are shown in Table 5-4. Typical mud components used in seawater-lignosulfonate drilling fluids are illustrated in Table 5-5, showing the well depths in which the various components are used.

The variability of estimated drilling mud useages is illustrated by the previous calculations which estimated total drilling mud use for the 4 proposed exploratory wells as 801 tonnes whereas Table 5-5 indicates that mud use for the four wells would be about 1041 tonnes. (Table 5-5 indicates mud use to drill to 3048 m as 333 tonnes. Interpolation with that figure to a total depth of 9540 m yields 1041 tonnes.)

The different sources from which the estimated useage rates were obtained stressed that the actual use of drilling mud could vary by as much as 50% in the field. As such, our estimated figures calculated from the different sources compare rather well, the variability between them being about 30%. However, the figures are certainly within the same order of magnitude, our intent not being to predict exactly the useage, but rather the general magnitude of the potential impact to the marine environment.

One of the most detailed studies yet conducted on the dispersion and impact of drilling mud disposal from off-

Table 5-3.

Mud composition by type (Adapted from Frazier *et al.*, 1977)

Mud Type	Components Used	Weight (kg.)	%
I Gelled Seawater	Attapulgite Clay	25,537	81
	Caustic (NaOH)	2,495	8
	Organic Polymer	1,678	5
	Ferrochrome Lignosulfonate[1]	1,497	5
	Pregelatinized Starch	227	0.7
	Seawater	(As Required)	
	TOTAL	31,434	
II Lignosulfonate Mud:	Barium Sulfate	144,696	81
	Caustic (NaOH)	10,206	6
	Ferrochrome Lignosulfonate	13,426	8
	Organic Polymer	1,860	1
	Bentonite or Attapulgite Clay	7,756	4
	Defoamers	147	0.1
	Water	(As Required)	
	Total	178,092	

1 (Iron: 2.6%, Chromium: 3.0%, Sulfur: 5.5%)

Table 5-4.

Typical mud additives (Adapted from Anon, 1974a. and Frazier et al., 1977).

Function	Name	Amount (kg/l)
pH Control	Caustic	$2.85 \times 10^{-4} - 8.56 \times 10^{-4}$
	Sodium Bicarbonate	$2.85 \times 10^{-4} - 4.28 \times 10^{-3}$
	Calcium Chloride	$2.85 \times 10^{-4} - 8.55 \times 10^{-3}$
	Calcium Hydroxide	$1.43 \times 10^{-3} - 2.20 \times 10^{-2}$
Corrosion Inhibition	Calcium Hydroxide	$1.43 \times 10^{-3} - 2.30 \times 10^{-2}$
	Sodium Chromate	$2.85 \times 10^{-4} - 1.14 \times 10^{-2}$
	Amines	5.70×10^{-3}
Defoamers	Aluminum Stearate	$2.85 \times 10^{-3} - 2.85 \times 10^{-2}$
	Alkyl Aryl Sulfonate	$5.70 \times 10^{-4} - 8.56 \times 10^{-4}$
	Silicones	$2.85 \times 10^{-4} - 8.55 \times 10^{-3}$
Emulsifiers	Calcium Lignosulfonate	$2.85 \times 10^{-3} - 1.14 \times 10^{-2}$
	Oxyethylated Alkyl Phenol	$1.43 \times 10^{-3} - 8.55 \times 10^{-3}$
	Ferrochrome Lignosulfonate	$2.85 \times 10^{-4} - 5.70 \times 10^{-3}$
	Quebracho	$5.70 \times 10^{-4} - 1.43 \times 10^{-2}$
Filtrate Reducers	Bentonite	$1.43 \times 10^{-2} - 2.85 \times 10^{-2}$
	Sodium Carboxymethyl cellulose	$2.85 \times 10^{-4} - 4.28 \times 10^{-3}$
	Sodium Polyacrylate	$2.85 \times 10^{-3} - 8.55 \times 10^{-3}$
	Starch	$5.70 \times 10^{-3} - 2.30 \times 10^{-2}$
Foaming Agents	Alkyl Polyoxyethylene	$2.30 \times 10^{-2} - 4.57 \times 10^{-2}$
Lost Circulation	Cottonseed Hulls	$8.55 \times 10^{-3} - 7.13 \times 10^{-2}$
	Cane Fiber	$5.70 \times 10^{-3} - 1.71 \times 10^{-2}$
	Asbestos	$5.70 \times 10^{-3} - 1.71 \times 10^{-2}$
	Cellophane	$1.43 \times 10^{-2} - 2.85 \times 10^{-2}$
	Mica	$5.70 \times 10^{-3} - 2.85 \times 10^{-2}$
Lubricants	Oxidized asphalt	$8.55 \times 10^{-3} - 1.71 \times 10^{-2}$
	Carbon Powder	$2.85 \times 10^{-3} - 5.70 \times 10^{-3}$
Shale Control	Oxidized asphalt	$8.55 \times 10^{-3} - 1.71 \times 10^{-2}$
	Calcium Hydroxide	$1.43 \times 10^{-3} - 2.3 \times 10^{-2}$
	Sodium Silicate	$2.85 \times 10^{-4} - 8.55 \times 10^{-3}$
	Calcium Lignosulfonates	$2.85 \times 10^{-4} - 8.55 \times 10^{-3}$
Surface Active Agents	Oxyethylated Alkyl Phenol	$1.43 \times 10^{-3} - 8.55 \times 10^{-3}$
	Alkyl Aryl Sulfonate	$5.70 \times 10^{-4} - 8.56 \times 10^{-4}$
Thinners	Sodium Tetraphosphate	$2.85 \times 10^{-4} - 5.70 \times 10^{-4}$
	Calcium Lignosulfonate	$2.85 \times 10^{-3} - 1.14 \times 10^{-2}$
	Sodium Chromate	$1.43 \times 10^{-3} - 8.55 \times 10^{-3}$
	Quebracho	$2.85 \times 10^{-3} - 2.85 \times 10^{-2}$

. . ./2

Table 5-4 (Continued)

Function	Name	Amount (kg/l)
Flucculants	Acrylamide Polymeric Hydrolite	2.85×10^{-5}
	Bentonite	$2.85 \times 10^{-3} - 1.43 \times 10^{-2}$
	Lignosulfonate	$2.85 \times 10^{-3} - 1.43 \times 10^{-2}$
Viscosifiers	Bentonite	$2.85 \times 10^{-3} - 1.43 \times 10^{-2}$
	Asbestos	$5.70 \times 10^{-3} - 1.71 \times 10^{-2}$
	Sodium Carboxymethyl Cellulose	$2.85 \times 10^{-4} - 4.28 \times 10^{-3}$
Bacteriocides	Paraformaldehyde	$1.43 \times 10^{-3} - 2.85 \times 10^{-3}$
	Sodium Chloride	$1.43 \times 10^{-2} - 2.85 \times 10^{-2}$
	Sodium Chromate	$2.85 \times 10^{-4} - 1.14 \times 10^{-2}$
Calcium Removal	Sodium Bicarbonate	$2.85 \times 10^{-4} - 4.28 \times 10^{-3}$
	Sodium Carbonate	$1.43 \times 10^{-3} - 5.70 \times 10^{-3}$
	Sodium Hydroxide	$2.85 \times 10^{-4} - 8.55 \times 10^{-3}$
	Organic Phosphate	$2.85 \times 10^{-4} - 1.43 \times 10^{-3}$

Table 5-5.

Components of mud as shown by drilling depth (Adapted from Frazier *et al*. (1977) and Anon (1974b.) Weights in kg.[1], to a total depth of 4572.00 m).

Mud Component	0-1066	1066 - 3048	3048 - 4572	kg	Tonnes
Barium Sulfate (Barite)	2,722	239,950	283,495	562,167	526
Bentonitic Clays	9,072	16,330	4,082	29,484	30
Attapulgite Clays	4,536	-	-	4,536	4.5
Caustic	454	9,072	10,433	19,958	20
Aromatic Detergent	454	907	-	1,360	1.4
Organic Polymers	454	1,361	-	1,814	1.8
Ferrochrome Lignosulfonate	-	1,179	31,298	43,091	43.
Sodium Chromate	-	-	907	907	0.9
	17,692	268,799	330,215	663,317	627.6
		(282 tonnes)[2]			

1 Quantities may vary by as much as 50% depending on specific drilling conditions.

2 Range of depth Anticipated for Baffin Bay

well was drilled from a semi-submersible drilling platform in 63 m of water in at a site designated as a "unique biological area". The well was completed in 90 days to a depth of 3419 m (11,217 ft.). Mud and cuttings were discharged 12 m below the surface at an average rate of 10-15 bbl/hr and totalled 4332 bbl (689 m^3).

Studies of the discharge indicated that pH, temperature, salinity and dissolved oxygen were at background levels 30 m from the point of discharge. Turbidity was affected (resulting in a persistent visual plume which extended out to 4 km or more), however, suspended solids concentrations reached background levels within 200 m of the source as did trace metals (Table 5-6). The persistent visual plume was ascribed to"very fine clay particles....extremely light reflective".

Settling and dispersion of the drilling fluids was found to be very rapid with mud and cuttings diluted from 500:1 to 1000:1 within 3 m of the discharge and increasing another 100:1 within 100 m. At the point of discharge the coarser particles of cuttings settled immediately while the finer materials moved horizontally and vertically outward. Dispersion characteristics such as this could be expected for the proposed Baffin Bay drilling program. Detection of the waste beyond 300 m of the discharge point would be difficult and, in some cases, probably impossible.

Ray (1978) summarized the literature on drilling mud toxicity, both for drilling fluid components (Table 5-7) and whole muds from field samples (Table 5-8). He noted that the relatively low concentrations of toxic components in the actual effluents mitigates against toxic effects of the whole effluent especially when one recognizes the rapid dilution of the wastes discharged.

The types and concentrations of drilling mud compounds employed will be discussed with the appropriate regulatory agencies in advance of commencement of drilling and only approved compounds and procedures will be used during the drilling. As such, the drilling practise anticipated for Baffin Bay will meet, or exceed, standards of practise established for other Arctic regions.

5.2.2 Waste Disposal (Solid and Domestic)

Petro-Canada will ensure that loadings from sewage effluents meet, or exceed, the standards set by the appro-

Table 5-6.

Selected Samples - mud and cuttings study (Adapted from Anon, 1978).

I Hydrographic Samples

Parameters	Distance from Discharge			
	8 m	60 m	75 m	Controls (Averages)
% Transmittance	26	75	15	93
Depth (m)	3.2	1.9	1.8	1.6
Temperature °C	14.6	14.8	14.7	14.7
Dissolved Oxygem (mg/l)	8.8	8.6	7.5	9.26
Salinity °/oo	33.9	34.1	33.9	33.8
pH	8.17	8.19	8.18	8.17

II Suspended solids and selected trace metals in whole mud and in the water column (mg/l)

Parameter	Whole Drilling Mud Sample	Distance from Discharge			
		2-3 m	100 m	200 m	Control
TSS[1]	250,000[2]	499	5.2	2.1	1.5
(Ba)	15,000	23	0.04	0.05	0.05
(Cr)	320	1	0.004	0.002	0.0004
(Pb)	26	0.05	0.005	0.004	0.0004

1 Suspended solids and trace metals sampled in densest areas of plume

2 Calculated mean

Table 5-7.

Representative bioassay results (96 hr TLM; concentration mg/l) (Adapted from Ray, 1978).

Drilling Mud Component	Concentration	Organism
Barium Sulfate	100,000[1]	White Shrimp[2]
Bentonite	10,000	Rainbow Trout[3]
Formaldehyde	28	Salmon[3]
Lignite	24,500	Sailfin Molly[3]
Lignosulfonate, Chrome	1,925	White Shrimp[2]
Lignosulfonate, Iron	7,800	White Shrimp[2]
Polyacrylate	3,500	White Shrimp[2]
Sodium Acid Pyrophosphate	1,200	Sailfin Molly[3]

1 100% survival even at maximum concentration noted.

2 Saltwater

3 Freshwater

Table 5-8.

Representative whole mud bioassay tests (mg/l, 96 hr TLM) (Adapted from Ray (1978) from E.P.S. Working Group A).

Organism	Component				
	KCI-Polymer Mud	Seawater/ Polymer	KCI-XC Polymer	Weighted Polymer	Weighted Gel/XC Polymer
Salmo Gairdneri (Rainbow trout)	24,000	-	-	-	-
Oncorhynchus kisutch (Coho salmon)	29,000	130,000	20,300	15,000	190,000
Oncorhynchus keta (Ehum salmon)	24,000	-	-	-	-
Nereis vexillosa (worm)	37,000	220,000	41,000	23,000	320,000
Mya Arenaria (clam)	42,000	320,000	56,000	10,000	560,000
Hemigrapsus nudus (crab)	53,000	530,000	78,000	62,000	560,000

priate government regulatory agencies. Rapid dilution will occur in any waste disposed from the drillships and, although nutrient concentrations in the effluent will be high, no significant effects on oceanic areas would result from such relatively miniscule additions.

The disposal of solid wastes will be carried out so as to fully comply with the appropriate standards and regulations. While current and proposed regulations for waste disposal from drilling units do not prohibit the dumping of solid or domestic wastes (except for non-combustible trash) in anticipation of the proposed International Regulations stipulating that no solid domestic or industrial wastes "shall be placed within 12 nautical miles of land and no floating material within 25 nautical miles ..." Petro-Canada is actively reviewing the feasibility of meeting the proposed regulations in advance of their promulgation.

5.2.3 Spills of Chemicals

In the process of normal offshore drilling operations rig wash water, cooling fluids, rig lubricants and washing compounds will be employed. Petro-Canada is prepared to list all the compounds expected to be used and to submit all toxicological data available for such chemicals. In all cases, collection and discharge of these compounds will be done in accordance with regulatory approvals.

The procedures for transfer of fuel oils to or from aircraft of any ships of the drilling fleet will be elaborated in the contingency plan and wherever possible "fail-safe" procedures for the systems used will be employed. If small volumes of fuel oil are lost the expected environmental impacts would be minimal because of the evaporative or dispersing potential of the volatile petroleum.

It is not expected that any major spills of fuel oil would ever result from the drilling fleet except in the extremely unlikely event of the loss of a large vessel. If a maritime disaster were to occur, the contingency planning against an oil blowout, which will be in place by the time of any commencement of drilling, would be more than able to respond to the relatively smaller volumes of oil spilled from a vessel.

As the proposed drilling program is restricted to exploratory techniques, no oily production water is contemplated for disposal. However, production testing could produce minor controlled quantities. This topic would be dealt with in any future, expanded submissions for drilling authorities should activity beyond the exploratory phase be contemplated.

5.2.4 Associated Effects

During the drilling of the exploratory wells it is not anticipated that the presence of the drillships or support vessels will cause any major disturbance to animal populations. It is possible that the noise levels associated with the drilling operation may cause some marine mammals to avoid areas of ocean near the ship, however, such effects are not considered to result in any significant impact on mobile animal populations.

Ice reconnaissance and standard resupply shuttle flights to the drillship will necessitate the presence of aircraft, both fixed and rotary-wing, throughout the drilling region. Flight lines to and from the supply depots and the ships will be drawn up in consultation with Government regulatory agencies and will meet with all prescribed limits to operations.

Bird colonies near flight lines will receive special consideration and attention throughout the active drilling period so as to minimize any impacts from aircraft disturbance. All pilots operating in the area will be briefed about sensitive areas and will be fully cognizant of flight restrictions or operating procedures in those vicinities.

In this regard, Petro-Canada has successfully operated extensive, logistical air operations in the region during the 1978 summer field season. The experience gained during 1978, and that expected to derive from the 1979 season of field activities throughout the Lancaster Sound-Baffin Bay region, will allow Petro-Canada to have experienced flight and ground crews ready for the proposed drilling-support operations.

"Real-time" experience in the region and practical experience of its sensitivities to disturbance are exceedingly valuable in terms of operational capabilities. Petro-Canada intends to expand the base of trained personnel for the regional operation so that optimal capabilities will be realized should operational support be required.

5.3 ENVIRONMENTAL IMPACTS FROM BLOWOUTS

5.3.1. The Analysis of Threats

A considerable literature has been developed in the recent past on the analysis of risks from an oil blowout in the Arctic marine environment. Statistical approaches have been the main thrust of such risk analyses developed by both government and industry (Imperial Oil Ltd. *et al.*, 1978; Norlands Petroleums Ltd., 1978; Bercha, 1977).

There are numerous objections to such hypothetical scenarios being applied to any specific drilling application, the chief one among those being the assumption that past drilling experience is directly applicable to a proposed development. Insofar as the drilling proposal for Baffin Bay - Lancaster Sound is concerned one could say that offshore exploratory drilling technology has developed substantially in the last decade with commensurate improvements in well control and the depths of water which can be worked. On the other hand, there is no drilling experience in the sedimentary deposits of Baffin Bay and it is problematic as to whether or not the drilling experience in deep, icy waters off Labrador and west Greenland can be applied to this proposal. Considerations of potential disruptions to the drilling resulting from ice intrusions or atmospheric disturbances are presently under examination by Petro-Canada for the specific drilling sites proposed for Baffin Bay.

The question of weighting of these several variables in statistical calculations based on historical data emerges as a serious consideration for any hypothetical analysis of drilling success in Baffin Bay. As Megill (1977) points out, judgements used in simulations as probability distributions can be summed to a final distribution which simulates our concept of risks. This analysis is only as good as the input to it and will only account for variables which are addressed in the summation. The elucidation of the key variables and their quantification in the analysis are, therefore, the prime determinants of the utility of the work. In short, as Megill notes, "If it happens, you must admit that it was possible!". Such considerations are not limited only to the construction of worst-case scenarios for oil exploration but extend into petroleum reservoir estimations, as well. Estimates of reservoir size directly influence leasing

strategies but because of the significance of reserve estimates the greatest possibility for errors in those estimates will always exist in frontier basins. As such, it is necessary to distinguish between Monte Carlo simulations and a risk analysis, the former being a mathematical model used to synthesize the analysis of the risks.

While risk analysis is one of the oldest techniques of business management science it is only relatively recently, with the regulatory requirements for predictive assessments, that this well-developed technique has been applied to environmental concerns. However, even in the former well-developed arena of business management it is easy to misapply the technique. Carter (1972) discussed the technique in detail and found that there were many problems, not the least of which centers on the tendency of managers to "bend" risk analysis to purposes which suit their specific interests. Hall (1975) further stated that risk analysis has not been widely successful because managers were more inclined to abandon a formal analysis of risks by substitution of more effective methods for coping with the consequences of the risks. The author succinctly noted: "Theoretically, the idea of quantifying uncertain elements in decision-making is hard to dispute - both on the grounds that this procedure brings more information into the analysis and on the grounds that the procedure makes assumptions and differences of opinion explicit. In practice, however, the idea fails on at least two grounds:

(1) The decision as to who should quantify uncertainty and how this should be done.

(2) The decision as to what uncertainties should be quantified."

If, in the relatively easily definable world of investment planning, quantitative tools for analysis of risks are often superceded by qualitative "judgemental" skills, consider how difficult quantitative assessments become for environmental considerations which have far more unknowns and uncontrolled variables than any man-made financial process. Considerations such as these led Kates (1977) to comment that "people have always assessed environmental threat: storm, drought, fire or disease. But for the new and newly-discovered hazards, there is a high perception of risk but little experience with the consequences. With such uncertainty it is not surprising that risk assessment practice is still more art than science and that distinctive, contrasting ideologies fluorish."

At the same time, a growing public perception of environmental hazards (a phenomenon which has largely occur-

red since 1964) has led in the past 30 years to an increase of public concern over technological "alarms". Kates (1977) concluded that while "The dramatic increase in perception (of threat) seems to be in anticipation of, rather than in response to, a marked deterioration of the security of life" the data, nevertheless, indicates that of 45 major public alarms over technology in over 25% of the cases the threat was not as great as originally described by opponents of the technology. However, "in over half of the cases, the threat was probably greater than admitted by the proponents of the technology and the problem was allowed to grow." Even more disturbing was the finding of researchers that even if technology assessments had been done they were judged to be "surely helpful in only about 40% of the cases." Findings such as these point out a need to, perhaps, spend some time examining the basis upon which wide environmental surveys are predicated.

In summary, risk analysis uses the best judgments and quantitative estimates available for a given project and translates them into the mathematical language of probability. The analysis is at best only a tool used to assist in the process of formulating reasonable decisions where key variables have a high degree of uncertainty.

In the specific case of the Lancaster Sound - Baffin Bay drilling proposal, it must be admitted that it represents an extreme example of a low probability event (an oil blowout) which could cause considerable environmental disruption to some of the animal populations of the region. Since any analysis uses many judgemental assumptions, by definition, and because of the difficulty in constructing a hypothetical environmental impact scenario from the probable events the utility of such speculations have been called into question. Milne and Smiley (1977) judged that the number of offshore blowouts worldwide which produced substantial pollution from oil is too small to "produce a satisfactory statistical base", however, they judged the oil or gas well blowout probability to be in the range of 10^{-3} to 10^{-4} for each well drilled in the Beaufort Sea. In their analysis of the Lancaster Sound area Milne and Smiley (1978) analysed data available up to 1972 which indicated that out of 20,373 offshore wells drilled approximately 2 in every 1,000 wells drilled had blowouts and that approximately 1 well in 3,300 blew oil. The authors went on to consider the drilling records of Panarctic and Canmar drilling, the former of which had a blowout (land-based) record of over 4 in 1,000 up to 1975. The latter have logged a considerably higher rate in the shallow Beaufort Sea basin at the close of the 1978 drilling season.

Norlands Petroleum (1978) summarized data from Goodwin (1972) which estimated a blowout frequency for U.S. offshore wells at 2 per 1,000 wells drilled and 5 blowouts per 1,000 wells drilled in the North Sea. More recently, the Canadian Arctic Resources Committee (1978) summarized data available from numerous sources on blowouts including the detailed analysis of Bercha (1977). The latter analysis indicated that about one well in every 300 drilled offshore blew out, but Bercha noted that all of the blowouts occurred during development drilling or field delineation drilling. No blowouts were reported from exploration wells drilled offshore. Furthermore, of the wells which blew out 63% stopped flowing independently because the well bore became clogged with debris and 17% were plugged by crews circulating heavy mud to the hole. Relief well drilling was required for the remaining 20%.

Imperial Oil (1978) indicated that of the wells offshore which have blown out 90% involved gas only and that a major spill of oil (in excess of 50,000 barrels) would, based on Bercha's analysis, have a probability of about one for every 10^6 wells drilled. Norlands Petroleums (1978) summarized Bercha's (1977) data on blowout probabilities (Table 5-9). The conclusion reached was that a blowout of oil, as a result of drilling activities from drillships, had a very low range of probability of occurrence (4.8×10^{-3} to 6×10^{-6}).

Milne and Smiley (1978) make the valid point that an over-reliance upon strict probability estimates based on so little Arctic, offshore drilling experience can be misleading: "Statistically, oilwell blowouts have occurred five times more frequently offshore than on land. Should this factor of five be applied to Lancaster Sound, the blowout rate would be 20 in 1,000. It is evident that the manipulation of past scores to predict future accidents soon becomes meaningless." They concluded that "...imprecise as it may be, we assume that the probability of an oilwell blowout in Lancaster Sound is somewhere between 1 in 1,000 and in 1 in 10,000."

The point here is not to belabour the reader with probabilities on blowout statistics, but rather, to demonstrate the ranges of the various estimates which have appeared in the literature. In addition to this it must be recalled that the cumulative probability of accidents increases with each successive well drilled as each well is an independent event. On the other hand, the experience gained from actual operations (for both drill crews, support personnel and government regulatory staff) tends to offset that probability.

Table 5-9.

Summary of estimates of blowout probabilities (Adapted from Norlands (1978) and Bercha (1977)).

Blowout Event	Event Probability per System-Year[1] SYSTEM & CONDITION		
	Summer		Winter
	Island	Drillship	Island
Blowout (all types)	1×10^{-3}	4.8×10^{-3}	1.2×10^{-3}
Small Oil Blowout (500 bbl)	1×10^{-4}	4.8×10^{-4}	1.2×10^{-4}
Intermediate Oil Blowout (500-5000 bbl)	1×10^{-5}	4.8×10^{-4}	1.2×10^{-5}
Major Oil Blowout (5000-50,000 bbl)	1.3×10^{-6}	6.0×10^{-6}	1.5×10^{-6}
Major Oil Spill from (more than 50,000 bbl)	3.9×10^{-7}	1.8×10^{-6}	4.5×10^{-7}

1 Three wells per system-year

There are some data available for offshore drilling operations in icy waters, however, a complete review of the Canadian, Danish and U.S. (Alaska) experience is not available in the literature. There have been several offshore wells (5) drilled in the waters off west Greenland. In 1976 one well was drilled and during 1977 three companies each drilled one or more wells, apparently without incident (Imperial Oil et al,1978). The U.S. experience in Cook Inlet, Alaska indicates that in those relatively shallow waters, the performance of the industrial sector in preventing spills has steadily improved (Alaska Dept. Natural Resources, 1976, Table 5-10).

Indeed, spills of oil related to domestic transport and consumption often greatly exceeded spills related to industrial production or exploration activities in Cook Inlet. There are 14 permanent platforms operating in Cook Inlet from which the majority of development drilling takes place. The exploratory drilling was done from drillships and jack-up rigs. The exploratory drilling was done chiefly in summer during ice-free months (State of Alaska, personal communication).

Extensive offshore drilling activities have been carried out offshore Labrador and off Newfoundland and Nova Scotia in the past decade including limited activity in Hudson Bay (Energy, Mines and Resources, 1977). Approximately 140 offshore wells were drilled off Canada's east coast by 1976, for a total drilled footage of 538,000 ft. (164 km). Much of the drilling has taken place nearby, or inside of, zones of commercial fisheries activity (Energy, Mines and Resources, 1977) and many different types of drilling systems have been used (Table 5-11).

No critical analyses of the Canadian offshore drilling record are available in the literature, however, more recently summaries of "incidents" encountered during the drilling of offshore wells off the east coast have been documented (Energy, Mines and Resources, personal communication (Table 5-12).

More recently, a brief analysis of the drilling record in the Beaufort Sea has been made available (Fisheries and Environment Canada, pers. comm.) (Table 5-13). The drilling record from the Beaufort Sea offshore drilling program is not considered to be at all comparable with any drilling which might take place in Baffin Bay because the geological histories and water depths are very different in the two areas (F.E.A.R.O., 1978). It should be noted that since 1974 Panarctic Oils Ltd. has successfully drilled 9 offshore wells from ice-strengthened platforms in the High Arctic.

Table 5-10.

Oil spills in Cook Inlet, Alaska, (Adapted from Alaska Dept. Natural Resources, 1976).

YEAR	Oil Industry Volume Spilled (m^3)	Oil Industry Incidents	Other Sources[1] Volume Spilled (m^3)	Other Sources[1] Incidents
1949			5	0
1962	No Data	1		0
1964			No Data	0
1965	25	1		0
1966	772	28	5	13
1967	290	47	1590	26
1968	170	49	62	18
1969	146	21	993	12
1970	165	23	633	31
1971	12	12	285	15
1972	3	8	5	1
1973	4	6	5	1
1974	3	25	43	4
1975[2]	2	2	3	3
	1592	223	3629	124

1 Domestic use-related spills (ie. tanker transport of heating oil to settlements).

2 Through Aug. 21, 1975.

Spill Averages:	Oil Industry	Other Sources
Spill Average Size:	7.5 m^3	49.8 m^3
Total Spill Volume Last 5 years:	23.1 m^3	340.4 m^3

Table 5-11.

Types of offshore drilling units which have operated in Canadian waters (1966-1978). (Adapted from Energy, Mines and Resources, personal communication, Sept. 1978).

Type of Drilling Unit	Rated Water Depth (m)	Length of Operation in Canadian Waters	Number of Wells Drilled
Drillship	185	1966	2
		1971	1
		1976	2
		1977	6
		1978	7
Semisubmersible	200	1969-1973	23
	185	1967-1977	93
Dynamically-Positioned Drillship	300	1973-1976	11
	610	1975	1
	915	1976 and 1978	4
	1,000	1978	1
Barge	185	1969-1970	3
Self-Propelled Semisubmersible	305	1976	1
Jackup Rig	75	1977	5

Table 5-12.

Summary of "incidents" deemed most significant in the Canadian offshore drilling record (Adapted from Energy, Mines and Resources, personal communication, Nov. 1978).

Date	Platform Type	Location/Incident	Result
1966	Anchored Drillship	Pan Am Grand Falls H-09: High Seas.	Well discontinued before reaching reaching T.D. with B.O.P. closed.* Well subsequently relocated with a Semisubmersible and cemented off.
1969	Anchored Barge	Walrus A-71 Hudson Bay: Severe Storm	Anchor line break followed by riser, kill/choke lines break. Well abandoned with blind rams closed. Well relocated in 1970 with submerisble.* Operations resumed in 1974 B.O.P. discovered to have sustained damaged and have leaked salt water.
1971	Anchored Drillship	Leif E-38 Labrador Sea: Iceberg approached during storm.	Forced disconnect. 1973 Pelican drillship re-entered the well, cemented it and recovered the BOP stack (still sealed).
1973	Sedco J	Adolphus 2k-41 Grand Banks: Pack ice approached.	Forced to leave site. Well sealed with cement plugs to total depth. Well re-entered and completed in 1974.
1974	Pelican Drillship (dynamically positioned).	Gudrid H-55 Labrador coast: Growler collision damaged main screw.	Drillship maintained position. (Well report from EM&R incomplete.
1974	Havdrill Drillship (dynamically positioned)	Bonavista C-99 Northern Grand Banks: Riser Failure.	Well closed in prior to failure. 1975 drillship returned to well. Divers dove to record 329 m and recovery operation completed.

*Sic

Table 5-13.

Offshore Drilling Problem Histories in DIAND Jurisdiction Regions (Adapted from DIAND, pers. comm.)

Spud Date	Well	Incident	Result
Aug.8,1976	Hunt, Dome Kopanoar D-14	Shallow water flow from high pressure sands at 1867 feet.	- Well abandoned
Sept.27,1976	Dome,Gulf *et al.* Kopanoar M-13	In 1976 shallow water flow encountered. Well re-entered in 1978 and deepened.	- Well suspended in 1976.
Aug.11,1976	Dome,Gulf *et al.* Tingmiark K-91	High pressure at 10,000 ft. led to water flow and explosion in drill-ship mud unit lab.	- Drilling activities suspended after 30 days down-time.
Sept.21,1976	Dome, Hunt Nektoralik K-59	Poor weather. Well re-entered in 1977.	- Operations halted for 5 days. - Well completed and abandoned.
July 19,1977	Dome Kaglulik A-75	High pressure water-flow at 1911 ft. in 1978. Ice forces drill-ship off hole.	- Drillship pushed off hole for a week. Drillship returned, stopped the flow from the well and subsequently abandoned it.
July 10,1978	Dome,Gulf *et al.* Ukalerk 2C-50	Bad weather.	- 4 days of down-time at the close of the 1978 season.

In summary, suffice it to say that if offshore drilling is deemed to be technically feasible in Baffin Bay the possibilities of an oil strike being followed by a blow-out from an exploratory well are exceedingly remote. This estimate, however, is not based on a detailed, specific statistical review of the offshore Canadian drilling record in icy waters. More specific probability estimates will have to await sufficient drilling experience and subsequent detailed analyses. In light of the doubtful applicability of world-wide drilling statistics to the Arctic deep-water drilling situation, it is questionable as to whether or not such detailed statistical analyses add significantly to the impact prediction process.

5.3.2 Perspective on Oil Spills in North America

Harrald et al.(1977) summarized a National Academy of Science review on global budgets of petroleum entering the sea. The review was not geographically specific, however, estimated ranges for input sources are of interest. The inputs from offshore production were shown as among the lowest contributions of the estimated total budget (Table 5-14). Oil pollution incidents for the entire U.S.A. were shown as contributing over 54 million liters of hydrocarbons to inland and oceanic areas in 1975 (Table 5-15). Although offshore production facilities incurred 12.3% of the total incidents in that year, the volumes spilled by those facilities constituted only 0.5% of the total. Over 81% of the total volume contributed to the aquatic environment originated from vessels (45.9%), onshore production facilities (18.2%) and pipelines (17.3%).

Taken together such figures provide an overview of the principal contributors to aquatic oil spillages. The application of such figures, however, requires care in that proportionality of total spillages may not necessarily reflect the ecological dimensions of the impacts resulting from the sources. For instance, a relatively small spill in a highly sensitive area at a pivotal time for a major aquatic species may exert a profound effect on the local populations. Also, Harrald et al.(1977) cautioned about complacent acceptance of data which may not reflect potential, rapid changes in trends at a time when the production and transport of hydrocarbons may be undergoing profound readjustments.

However, general assertions as to the primary sources of hydrocarbon emissions can emerge from such data. The widely held concept of oil pollution originating primarily from tanker-transport systems is reasonably well-founded. However, smaller incremental additions from onshore production or barging systems rarely receive public attention yet many contribute substantially to the total effluent to

Table 5-14

Petroleum hydrocarbons entering the ocean (Adapted from Harrald *et al.* (1977).[1]

Sources	Inputs*			
	Best Estimate(%)		Probable Range	Estimated Gallons**
Marine Transportation				
Load on top tankers	0.31	(5.1)	0.15-0.4	
Non-L.O.T. tankers	0.77	(12.7)	0.65-1.0	
Dry docking	0.25	(4.1)	0.2-0.3	656 X 10^6
Terminal Operations	0.003	(0.05)	0.0015-0.005	
Bilges/Bunkering	0.5	(8.3)	0.4-0.7	
Tanker accidents	0.2	(3.3)	0.12-0.25	
Non-tanker accidents	0.1	(1.6)	0.002-0.15	
River Runoff	1.6	(26.4)	-	493 X 10^6
Atmospheric fallout	0.6	(9.9)	0.4-0.8	185 X 10^6
Urban Runoff	0.3	(4.9)	0.1-0.5	185 x 10^6
Coastal Municipal Waste	0.3	(4.9)	-	
Industrial Waste	0.3	(4.9)	-	154 X 10^6
Coastal Refineries	0.2	(3.3)	0.2-0.3	
Offshore Production	0.008	(1.3)	0.08-0.15	25 X 10^6
Natural Offshore Seeps	0.6	(9.9)	-	185 X 10^6
	6.041	100%		1,883 X 10^6

* Millions metric tons/annum

** U.S. gals (assumes 308 gal.(U.S.)/ metric ton)

1 Based upon world petroleum production and transport statistics for 1971, supplemented by domestic oil spill data for 1970-72.

Table 5-15.

Oil pollution incidents for the U.S.A. in 1975 (Adapted from Harrald et al. (1977)).

Source	Number of Incidents	% Total	Volume in litres	% Total
Vessels				
Dry Cargo Ships	277	2.7	82,685	0.2
Dry Cargo Barges	31	0.3	19,741	0.07
Tank Ships	643	6.3	6,687,797	12.2
Tank Barges	757	7.5	13,124,791	24.0
Combatant Vessels	202	2.0	64,023	0.1
Other Vessels	1,143	11.3	5,125,247	9.4
Sub-Total	3,053	30.1	25,104,284	45.97
Land Vehicles				
Rail	27	0.4	2,182,316	4.0
Highway	263	2.6	1,349,882	2.4
Other	20	0.1	9,906	0.02
Sub-Total	310	3.1	3,542,104	6.42
Stationary Facilities				
Onshore Refinery	176	1.7	55,168	1.0
Onshore Storage	305	3.0	1,804,673	3.3
Onshore Production	233	2.3	9,943,918	18.2
Offshore Production	1,243	12.3	296,084	0.5
Other	762	7.5	2,149,827	4.0
Sub-Total	2,719	26.8	14,249,670	27.0
Pipelines	564	5.6	9,426,573	17.3
Marine Facilities				
Onshore/Offshore Bulk Transfer	250	2.5	307,387	0.6
Onshore/Offshore Fueling	74	0.7	35,537	0.065
Onshore/Offshore Cargo Transfer	19	0.2	5,020	0.009
Transport-related marine facility	80	0.8	27,403	0.05
Sub-Total	423	4.2	9,801,920	0.724
Land Facilities	167	1.6	760,724	1.5
Misc./Unknown	2,905	28.6	704,253	1.3
Total	10,141	100	54,162,955	100

waters. Certainly, blowouts from drilling platforms or vessels appear to have received a disproportionate amount of public attention relative to transportation losses. The reasons for this are unclear, but may be related to the international nature of shipping and the diffuse regulations or penalties throughout the world which regulate the shipping or impose restrictions upon it.

In another, similar review Frazier et al.(1977) noted that accidental losses of oil to the oceans account for about 10 percent of the 2.1 million metric tons of oil estimated to reach the world's oceans each year (Anon, 1975a). The estimate of 2.1 million metric tons may be conservative as the U.S. Bureau of Land Management estimates that the figure may reach as much as 5 million metric tons/year, especially when one includes discharges from waste oil effluents and refinery or petrochemical operations.

About 103,000 metric tons/year has been estimated as originating from offshore drilling and offshore production facilities, of which accidents such as blowouts contribute about 29,500 metric tons/year (Kash et al.,1973). The natural seepage of oil to the oceans is estimated at less than 200,000 metric tons/year (Anon,1970). Frazier et al.(1977) found that in drilling 14,000 offshore wells from 1937-1970, of which 9,000 were on the outer continental shelf, 25 blowouts occurred (Table 5-20).

Their study indicated that over 90% of oil spill events introduce less than 50 barrels of oil into water, however, where large spillages occur enormous quantities of oil may be lost. The spill from the Torrey Canyon tanker accident in 1967 was cited as having released twice as much oil in one spillage than was estimated to have been spilled in all the United States in 1970.

In the decade from 1964-1974 the U.S. oil and gas operations on Federal Outer Continental Shelf Lease areas in the Gulf of Mexico and off California accounted for spillages of more than 50 barrels in 44 and 1 incident, respectively. These incidents included blowouts, platform fires, storm or ship damage, pipeline failures and barge leaks (Anon,1975b). Frazier et al.(1977) found that the statistics from the Gulf of Mexico indicate that one well blowout occurs for each 2,860 wells drilled and that about 2,100 barrels of oil are lost in that blowout. Further, the potential for accidents was greater during drilling and "workover operations" than during normal production operations and most of the events were associated with human error.

In order to place such incidents in perspective one must consider the offshore drilling experience in North America. The number of wells drilled on the U.S. outer continental shelf area (O.C.S.) is considerable. Frazier et al.

(1977) who cite data on the projected U.S. activity for the period 1975-1980 (Table 5-16). By comparison, the statistics for offshore well drilling in California, Texas and Louisiana for 1973-1974 indicate 1,950 exploratory-development wells drilled and for 1975-1976 as noted in Table 5-17.

From 1969-1975 U.S. offshore production of crude oil and condensate originated primarily (73%) from offshore Louisiana (Table 5-18).

U.S. production reached a maximum in 1971 with 614 million barrels delivered from offshore as compared with total U.S. production which peaked in 1970 at 3.52×10^9 barrels. That production has declined continuously and reached 3.05×10^9 barrels in 1975. In percentage terms, U.S. offshore production reached a maximum of 17.8% of total production in 1971, decreasing to 16.4% in 1975.

In summary, while North America offshore exploration and production of oil has contributed substantially to reserves of petroleum, the incidents of spills originating from that production is exceedingly small - far less proportionately than that related to vessel transportation losses. The decline in the productivity of those reservoirs certainly reflects the drive for new frontier exploration and development of petroleum (refer to Section 2.2). While it is necessary to evaluate the risks from blowout potentials in the Arctic, any such evaluations should be made in light of the substantive production or exploration experience of offshore drilling in North America.

5.3.3. Oil Blowouts

Blowouts may occur at the surface of offshore drilling operations or subsurface. The former is a spectacular event often accompanied by a loss of petroleum hydrocarbons and sometimes by fire or explosions while the latter may be much less spectacular. However, it may be very difficult to control subsurface blowouts and, while leaving no impression on the surface, they may devastate a hydrocarbon reservoir structure.

A sudden influx of formation fluids into a wellbore is termed a "kick". When fluids such as oil, water or gas enter the wellbore prompt action by drilling crews must be taken so as to maintain control over the well. A blowout, therefore, is an uncontrolled "kick". Kennedy (1971) conducted a limited survey of specific wells when control was lost in offshore and onshore situations. The study was revealing indicating that "loss of control" is a matter of degree as some problems are more difficult to resolve and having varying effects. It was found that of the 32 wells surveyed with control problems encountered while drilling, 19 were develop-

Table 5-16.

Projected U.S. Offshore Drilling Activity (1975-1980).

Offshore Region	Total Holes to be Drilled
Alaska	1017
Pacific Coast	5133
Gulf Coast	9583
Atlantic Coast	57
TOTAL	15,790

Table 5-17.

Wells Drilled offshore from 1975-1976 on the U.S. O.C.S. region.

	1975			1976		
	Total Wells	Total Wildcats	Footage (1000 m)	Total Wells	Total Wildcats	Footage (1000 m)
California:	69	4	83	95	25	106
Texas:	174	54	475	308	182	815
Louisiana:	641	168	1842	704	142	2944
	884	226	2400	1107	349	2965

Table 5-18.

Annual Production (Thousands of Barrels)(From Frazier *et al*.(1977) (Assumes 0.158 m^3/bbl)

Area	1969	1970	1971	1972	1973	1974	1975	1971-75
Alaska	60955	70080	66065	63744	61789	60308	60293	312199
California	95995	104390	101470	95578	89028	83918	79096	449090
Texas	2920	2920	2920	1611	1397	1081	779	7788
Louisiana	365730	398580	443840	446639	426784	398329	361052	2076644
Total U.S. Offshore	525600	575970	614295	607572	578998	543636	501220	2845721

ment wells, 10 were wildcats and 3 were extensions (Table 5-19).

It was found that the area of drilling will affect performance. For instance, all but one of the ten offshore wells studied from Louisiana lost control while drilling whereas on the U.S. West Coast, loss of control occurred on 75% of the wells while the drill stem was being raised out of the hole.

In every area from which data were obtained problems in development wells were significantly greater than that found for wildcat (exploratory) wells probably because wildcat wells are usually drilled with extra margins of safety. On the other hand, in production/delineation drilling, cost controls usually assume an increasing importance and as a result safety margins may be narrowed. The surprising conclusion is that "the most difficult wells appear to be drilled with as few well-control problems as the easier ones ...on the other hand, when they do occur, the fewer loss-of- control incidents on wildcats can be more serious...".

The survey further indicated that gas flows account for the bulk of the well-control problems encountered although salt water flows were frequent in some areas. Detailed analyses indicated that there were two primary areas where trouble was most probable: Soon after setting casing and as the hole nears the next casing point (Table 5-20).

The factors which contributed to the lack of success in regaining control of the problems were noted as being:

- poorly prepared/trained crews
- difficulty in recognizing pit volume changes on floating vessels in rough seas
- flows not detected early enough to allow for preventative measures
- no inside BOP in place
- loss of circulation

Reifel (1976) noted that "Blowout prevention is a frame of mind of the drilling crew and supervisory staff. The determination of operators and management to eliminate blowouts is far more valuable than any equipment used to control blowouts." The statement demonstrates that while equipment forms the first line of defense against uncontrolled flows, the training and capabilities of drilling crews will ultimately determine the success of such efforts.

The cause of "kicks" while drilling may be due to encountering very permeable formations which are unbalanced

Table 5-19.

Characteristics of control problems studied. (Adapted from Kennedy (1971)).

Details	Location							
WELL TYPE	Offshore La. (U.S.A.)	West Coast (US)	L/T[1]		Cook Inlet	Other	Total	% Total
Development	6	6	4	4		1	21	66
Wildcat	2	2	0	0	2	2	8	25
Extension	2	0	0	1			3	9
TYPE OF FLOW								
Oil	0	0	0			1	1	3
Gas	4	6	4	5	1	1	21	66
Saltwater	5	0	0		1		6	19
Combination	1	2	0			1	4	12
OPERATION AT INCIDENT								
Drilling	9	0	0	2	1	1	13	41
Going out of hole		6	3	3		1	13	41
Going in hole			0				1	3
Circulating, drilling after freeing pipe		1	1	1	1	1	3	9
Other	1	1	0				2	6

1 Louisiana - Texas, U.S.A.

Table 5-20.

Specific well control incidents (offshore). (Adapted from Kennedy (1971)).

Location	Type	Flow	Depth of Incidents (m.)	Operation during Incident
Cook Inlet	W	Saltwater	2770	Drilling
Cook Inlet	W	Gas	991	Circulating
Offshore La	D	Gas	2712	Drilling
Offshore La	D	Saltwater	3867	Drilling
Offshore La	D	Gas	4844	Drilling
Offshore La	D	Saltwater	5574	Resuming Drilling
Offshore La	W	Gas	3441	Drilling
Offshore La	E	Gas	4240	Drilling
Offshore La	D	Saltwater	4151	Drilling
Offshore La	D	Saltwater	3305	Drilling
Offshore La	W	Saltwater	6065	Shutdown
Offshore La	E	Gas	3047	Drilling
Offshore La	E	Gas	3898	Tripping

W = Wildcat
D = Development
E = Extension

by mud pressures or by fluid losses after pipe is removed from the well bore. Planning, execution and analysis of the well being drilled will tend to reduce the frequency of "kicks" and these procedures ultimately add to well control and prevent blowouts. The key to well control rests in maintaining a balance of pressure in the wellbore. Pressure underbalance, which may cause a "kick", may result from poor well planning, a failure to keep the hole full, swabbing, lost circulation or loss of mud weight (Reifel, 1976). If the "kick" becomes uncontrolled a blowout develops. These "kicks" may become uncontrolled because of a lack of early detection, a failure to take corrective action, lack of control equipment or well casing and a malfunction of the control equipment (Reifel, 1976). The latter problem area is extensively reviewed by Elkins (1976) and is, obviously, a matter of continuing interest among drilling engineers and an area where developing technology plays an important role.

The importance of well control equipment is a prime consideration in any drilling program, however, most blowouts occur as a result of human error. As such, the key to the prevention of blowouts rests with teaching drilling crews to maintain correct mud weights, rapidly detect the entry of foreign fluids into the wellbore and then be able to take prompt, appropriate action to remove that fluid from the well.

If a blowout occurs control may be regained once again by techniques that block the escaping reservoir fluid in the wellbore or down in the formation itself. A relief well may be drilled in the wild-well at which time heavy mud may be injected into the bore until control is regained. In cases where the bottom hole pressure exceeds that which can be offset by mud injection rates, the relief well may be aimed at a point off the wild-well so that mud can be injected into the reservoir so as to prevent escape of the fluids.

Reifel (1976) stated that after a wild-well is brought under control with a relief well, it may still be necessary to initiate "final plugging operations" in order to gain a permanent control over the well. The well may be cemented in and abandoned or temporary wellheads may be set until the well can be restored. Such restoration drilling programs may be exceedingly complex and costly. Reifel (1976) noted that four drilling rigs took 47 days to drill four relief wells to Amoco Platform B offshore Louisiana in 1971. The operation cost about $9 million to drill the wells, fight fires and control pollution. Other blowouts offshore Louisiana (Shell Platform B) took up to 136 days to control at a cost of about $28 million.

In the case of offshore drilling obviously, preventative measures are well worth the cost of implementation especially in the case of offshore drilling.

In the Arctic it could be expected that remedial costs would be considerably greater than for more southerly operations. For these and other, environmental reasons Petro-Canada considers it essential that drilling equipment and personnel be of the first order in terms of capability and experience, (Refer to Section 3.0).

The assessment of potential oil blowout characteristics is exceedingly difficult for the Baffin Bay area. Aside from the fact that we have absolutely no information available to us regarding sedimentary formation pressures, the types of dissolved gas or oils possibly present in those formations (or even of the existence of petroleum hydro- carbons in the sedimentary deposits), considerations about oil blowouts in depths of water exceeding 750 metres are further compounded by our lack of data about such occurrences.

The Department of Indian Affairs and Northern Development (DIAND) has determined that by 1979 all Arctic offshore drilling, including exploratory drilling, must be designed so as to include a same-season relief well drilling capability. Further, DIAND considers that analyses of seismic data only provide general information about the delineation of "over-pressured" geological offshore areas. As such, seismic data are considered as being unacceptable in arguments against having same-season relief well capabilities (DIAND, 1977). DIAND considers that same-season relief drilling could be achieved by "extending the season into winter" with a suitable ice-breaking vessel, however, Petro-Canada remains to be convinced of the utility of this system in Baffin Bay.

For the scenario of an oil well blowout in the Beaufort Sea, Milne and Smiley (1978) at least had available to them the extensive drilling experience from the offshore drilling programs which had been carried out in that region. No such data or drilling experience exist for Lancaster Sound or Baffin Bay. As a consequence of this, in their analysis of offshore drilling in Lancaster Sound, Milne and Smiley (1978) had to make several key assumptions regarding potential oil blowout flow rates:

(1) An oil flow rate of 950 m^3/day (6,000 barrels/day).

(2) The flow was assumed to emerge at the sea bottom, in 770 m of water, and remain constant until a relief well was drilled or until the well closed itself off.

(3) The volume of gas emerging was assumed as

being 3 times the volume of oil per day, or 2850 m^3/day.

(4) The oil was assumed to have the same physical/chemical characteristics as Norman Wells crude oil.

The assumed rate of flow of 6,000 barrels/day places the hypothetical blowout in Lancaster Sound as being somewhat greater than that which was estimated for the initial Santa Barbara spill (5,000 bbl/day). Assuming a weight of crude oil of about 0.8t m^{-3} a spill of 950 m^3/day (760 t/day) would, after 10 hours, occupy an area of open sea from 10^6 to $10^7 m^2$ according to the analysis of M.I.T. (1973). (This was calculated as a theoretical rate of spreading of oil on a calm sea. After 100 hours the maximum estimated area covered would be slightly more than $10^7 m^2$, which would not increase substantially, thereafter). Milne and Smiley (1978) concluded that the resultant oil slick from that volume of oil would initially be distributed in thin slicks in a patch about 3,200 m in diameter with an average slick thickness of from 0.12 - 0.50 mm. That theoretical oil slick 3,200 m across would occupy an area of about 8 x $10^6 m^2$, which compares well with the estimate based on the M.I.T. study (10^6 to $10^7 m^2$) for spreading of that amount of oil. (Fig. 5-1).

Studies done in the Beaufort Sea indicated that oil emerging freely underwater, without natural gas, breaks into droplets (2-10 mm in diameter) which slowly rise in a conical-shaped plume. However, as Milne and Smiley (1978) point out, Topham's work in the Beaufort Sea indicated that when gas and oil are ejected into sea water the droplets of oil produced are considerably smaller than 2-10 mm. The authors concluded it likely that, in Lancaster Sound, an underwater oil blowout would produce droplets ranging from 0-5 mm in diameter with most being from 1 to 3 mm across. In addition, the ascent of the oil droplets was predicted to quickly separate the oil from any gas.

Although studies are still in progress it seems likely that if gas is encountered in a deep water blowout, a considerable portion of it may form gas hydrates. Such hydrate formation could amount to up to 70 t/day or conversely, if the gas became super-saturated, the oil droplets could be shattered by expansion of gas contained within the oil droplets. Both of these hypotheses are under investigation. In the case of a deep-water blowout turbulent mixing would be expected to occur only near the water surface as water pressure near the blowout would tend to minimize gas expansion.

Milne and Smiley (1978) estimated that of the total amount of oil released 770 m below the surface only about 0.1% would dissolve into the water (0.95 m^3 day^{-1}),

RATE OF SPREAD OF OIL FOR SIX SPILLS (weight of spill in metric tons)

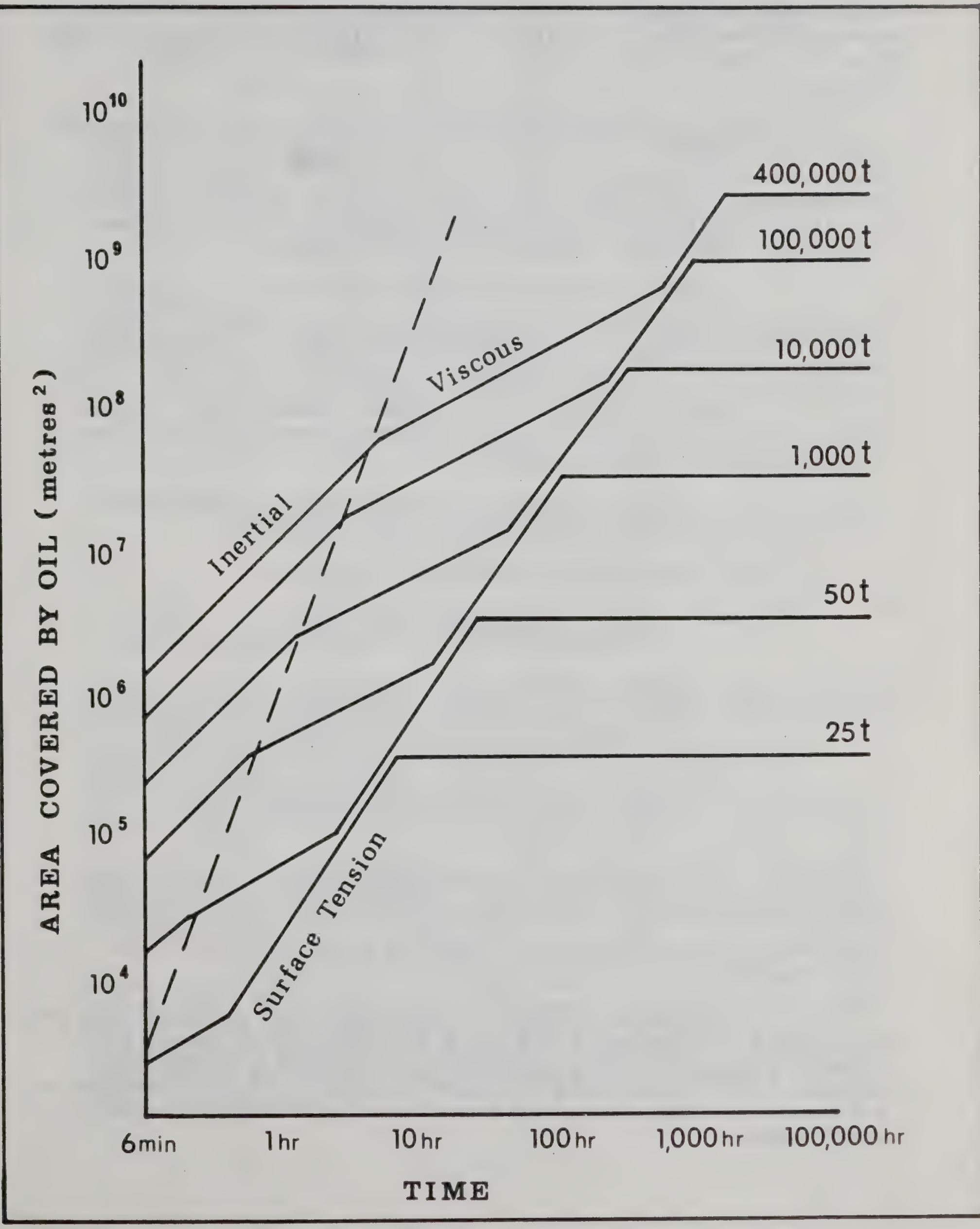


Fig. 5-1: Theoretical rate of spreading of oil on still water. (Adapted from Johnston 1977)

however, if shattering of the droplets occurred more oil would be dissolved. Since this amount of dissolved oil was calculated as reaching a maximum concentration of 20 ng/l it was concluded that the toxicity from dissolved oil resulting from oil rising through the water column would be negligible.

The vertical trajectory of an hypothetical blowout plume in Lancaster Sound was indicated by Milne and Smiley (1978) as being dispersed by currents while rising through the water column. The plume would produce a moving patch of oil at the surface in which up to 950 m^3/day would accumulate in an eliptical circuit about 400 m wide.

Sanborn (1977) considered that such oil spills in tte Arctic marine environment would exert a greater impact, for a longer time, than for comparable spills in sub-arctic regions. He reached this conclusion after considering that inaccessible and remote Arctic locations would present significant problems in salvage and cleanup operations. Factors which he then considered might increase the seriousness and duration of such spills were:

(1) Cold temperatures which inhibit the rapid evaporation of aromatic fractions.

(2) Bacterial degradation is slower.

(3) Photochemical oxidation would be reduced by limited daylight (fall-winter-spring).

(4) The marine biota is generally long-lived, has a low reproductive potential, and does not have wide-ranging dispersal stages.

(5) Arctic food chains are relatively short increasing their vulnerability to disruption.

He further noted that while ecological concern centers on species of economic importance, such as the marine mammals and waterfowl, "there is a great paucity of information on the forms that comprise the food web on which the higher forms depend."

In general, it may be said that the consequences of marine oil spills may range from few biological impacts through to catastrophic effects on localized populations. Sanborn (1977) discussed the many parameters which operate to influence the magnitude and duration of oil spills, some of which were:

(i) The type of petroleum spills (viscosity, aromatic content, etc.)

(ii) The dosage of oil spilled in a given area.

(iii) Oceanographic conditions (currents, wave action, coastal formations) which determine the movements and dispersal of the oil.

(iv) Meteorological conditions (winds as influencing the rate of movement (or mixing) and direction of the oil and factors such as evaporation).

(v) The biota which occurs in the area of the spill (morphology, reproductive strategy, feeding, age and distribution all influence susceptibility).

(vi) Season (as affecting biological distributions and frequencies of occurrence).

(vii) Previous history of exposure to oils (some oil-impacted colonies may be recovering and, therefore, be more susceptible to further impacts while some species may have begun to develop tolerances to chronic, low-level oil exposure).

Bruce (1976) echoed these concerns for Arctic environments and stated that "the absence of previous exposure is also a cause for concern, since arctic and subarctic organisms may lack defense mechanisms which have evolved in animals living in highly variable environments." He pointed out the problems involved in restricting considerations about impacts to spectacular, immediate consequences of oil spills: "...the first-order results may be of considerably less consequence in the long term than less conspicuous but longer acting lower-order ones, such as those arising from chronic low-level release of contaminants."

Recognition of the potential consequences from a major Arctic oil spill dictates that operating programs be exceptional in terms of the equipment and personnel so employed. Contingency planning, set out to augment these extraordinary measures in drilling programs, will also be required to be exceptionally capable at responding to emergency conditions.

5.3.4 Case Study of a Severe Oil Blowout

The Santa Barbara Channel oil blowout of January 28, 1969 originated from a Union Oil development well (A-21) located about 9 km south of Santa Barbara, California. The platform was located in about 190 feet (60 m) of water, the well having been drilled to slightly less than 1,070 m. The blowout of gas and crude oil erupted from fissures in oil-bearing formations on the sea floor in the vicinity of the drilling platform. Eleven days after the blowout the well was considered as being sealed off, however, the oil and gas leakage continued adjacent to the well.

Loutfi (1973) cites data which indicate that up to 5,000 barrels of oil (750 long tons) of oil were lost per day during the first 11 days, however, this figure was disputed as being 10 times larger than the estimate made by the oil company. If one accepts the estimate of Loutfi (1973) of 5,000 bbls/day, the rate of flow at Santa Barbara would be only slightly less than the estimate of Milne and Smiley (1978) of a hypothetical oil blowout in Lancaster Sound - Baffin Bay (950 m^3/day or 6,000 bbls/day). While it is recognized that the latter is highly speculative it is useful to have a comparative measure of a blowout experience in the south with the hypothetical "worst-case" analysis from Lancaster Sound.

It was estimated (Allen, 1969) that 100 days after the Santa Barbara blowout a minimum of 12,000 metric tons of oil had escaped into the ocean. Interestingly, Foster et al.(1969) thought that the actual maximum figure could be another order of magnitude greater. Such controversy indicates the difficulty of estimating oil losses from offshore wells. Among other difficulties, such as volumetric measure of the oil, Loutfi (1973) noted that the problems of volume estimation were compounded by the presence of natural oil seeps in the Santa Barbara Channel and the "politics" associated with the disaster. Loutfi (1973) further data which indicated that by May (4 months after the loss of control of the well) the flow rate was calculated as being 27 metric tons/day decreasing "to 4 metric tons or less per day by August, 1969."

Danenberger (1976) indicated that initial impressions about the consequences from blowouts may be misleading. Certainly, the publicity associated with such events tends to focus public attention on short-lived impacts. He noted that subsequent studies by the Allan Hancock Foundation "found that flora and fauna in the (Santa Barbara) Channel were damaged much less than had been predicted, and that the area is recovering well." While such assessments are hardly a justification for oilspill events associated with offshore drilling they, nevertheless, serve to balance impressions

about marine oilspills with wisdom derived from the perspective of time. This perspective is often missed by the media and the public at large, with the unfortunate consequence that it focusses interest and discussion on spectacular, short-term impacts. Long-term impacts of oil spills in the Arctic may, nevertheless be severe.

5.3.5 Case Study of a Severe Gas Blowout

Brooks et al.(1978) produced a detailed study of a severe gas well blowout which occurred in 95 m of water in the Gulf of Mexico about 160 km south of Galveston, Texas. While the water depths and geological substrata involved in their study were both probably different from that which may be encountered in Baffin Bay it is illustrative of the potential magnitude of the impacts or consequences of a gas well blowout.

The well had penetrated to 1800 m when control from a fixed drilling platform was lost. The incident eventually caused the platform to collapse as a result of the escape of high- pressure gas which created a sub-sea crater 500 m across and 130 m deep. The rate of gas seepage was estimated to be 10 X 10^6l/day for 6 weeks. The rising bubble plume was 75 m across and resulted in a surface plume "hundreds of meters across" consisting of suspended sediment and gas. At the above rate of flow, a total of about 420 X 1061 of gaseous and/or liquid hydrocarbons would have entered the marine environment.

Samples of water taken near the plume indicated a rapid dilution of the high dissolved hydrocarbon levels (primarily methane). The dilution occurred as the plume neared the surface and with distance away from the source. The hydrocarbons were rapidly diluted by the turbulent mixing in the waters and by volatilization of bubbles (1-5 cm^3 in size) surface. (Table 5-21). The blowout displaced several million tons of sediment into the water column, about 30% of which resettled into a crater which formed within 250 m of the blowout site (Fig. 5-2). Other sediment fractions remained suspended in the water column and were carried out of the area. Hydrocarbons were trapped in the redeposited sediment and methane levels were highest in those newly deposited. Methane concentrations decreased with distance from the source, which extended 5-6 km outward before reaching background levels. Large quantities of liquid hydrocarbons dissolved into the water column, estimated at 1 X 10^6g/day of which an estimated 14 kg/day escaped to the atmosphere (Fig. 5-3).

The study of this gas blowout event is of considerable interest as it provides a case history beyond which

Table 5-21.

Measurements taken 150 m from seep in plume (Adapted from Brooks *et al.* (1978))

Depth(m)	Methane (nl/l)	Ethane(nl/l)	Propane(nl/l)	*TSM(mg/l)
0	31 X 105	183 X 10^2	88 X 10^2	32.5
10	28 X 10^3	162	91	--
20	36 X 10^3	196	100	--
30	144 X 10^4	86 X 10^2	41 X 10^2	--
40	76 X 10^5	46 X 10^4	201 X 10^2	20.9
50	52 X 105	313 X 102	143 X 102	--
60	471 X 10^4	26 X 10^3	118 X 10^2	--
70	--	--	--	--
80	374 X 10^4	231 X 10^2	10 X 10^3	--
90	346 X 104	211 X 102	8920	--

* Total suspended matter as samples "over bubbles"

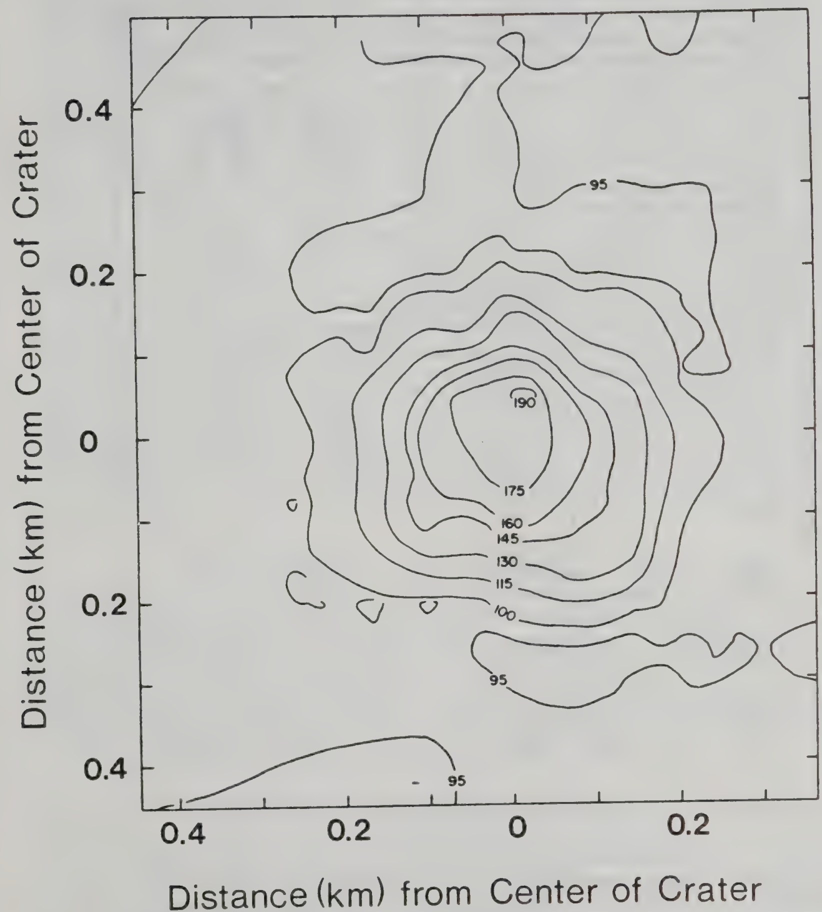


Figure 5-2
Bathymetry of blowout crater, 19 March 1977

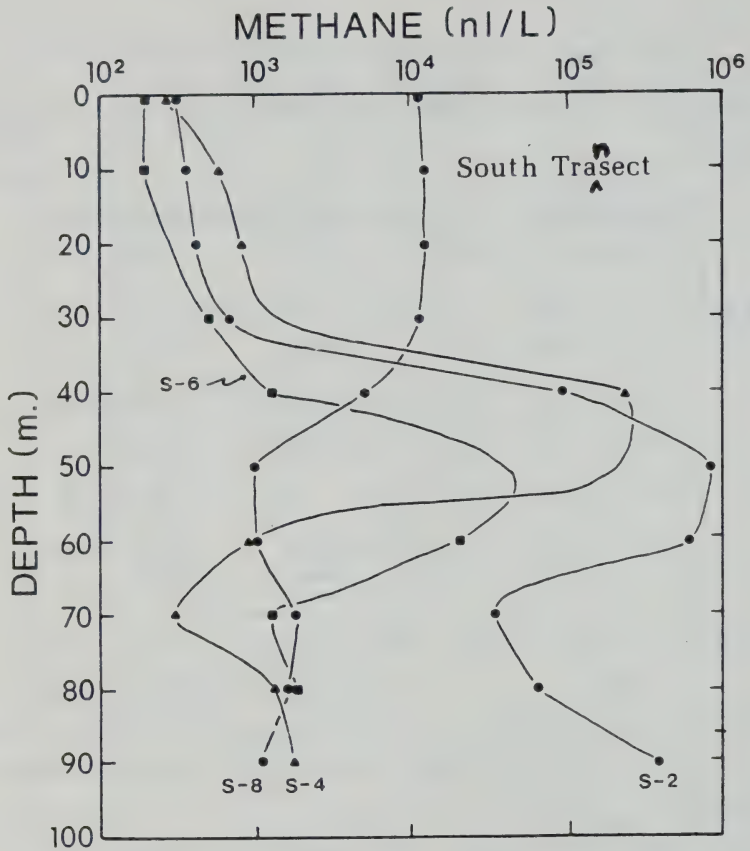


Figure 5-3

Methane concentrations at south transect water column stations (Station 2, 4, 6, and 8 are 200, 500, 2000, and 6000 m south of the centre of crater)

certain predictions can be drawn for Baffin Bay and Lancaster Sound. The principal hazards to the marine environment resulting from a gas blowout would involve toxicity from the hydrocarbons or hydrosulfates, damage to benthos from redistribution of sedimentary material and from the effects of increased turbidity in the water column. Light liquid hydrocarbons, especially light aromatics, such as toluene, benzene and xylene, represent the more toxic petroleum components. In the immediate vicinity of a blowout one can expect an increase in dissolved hydrocarbon levels, especially methane, and in suspended sediment. In deep water wells it is doubtful that the redistribution of sediment or increase in turbidity would have an appreciable effect on the marine environment as benthic communities would be very limited at that depth. Further, increased turbidity could be expected to decrease phytoplankter productivity (due to decreased penetration of light) only in shallow waters. Such an effect, if it did occur, may be offset by enhanced nutrient additions through turbulent mixing in the water. A greater quantity of liquid and gaseous hydrocarbons could be expected to become dissolved in the waters of Baffin Bay, than observed in the Gulf of Mexico, because of the much greater depth from which the blowout would arise. Deep-water gas blowouts would probably cause far less disruption to sediments as the dynamic action of the expanding gas would occur near the water surface and not at the highly pressurized region near the drill hole.

The potential for biological impacts from a gas blowout might be dramatically increased should the gas be accompanied by significant quantities of hydrogen sulfide (H_2S) (especially an under-ice blowout). Although detailed studies on the introduction of this type of gas to the marine environment from a blowout are not available, one could expect significant toxicity to marine organisms, possibly including marine mammals, where high dissolved contractions of this highly toxic gas occurred.

In a study of drilling operations in the North Sea Johnston (1977) considered that the uncontrolled escape of natural gas from the sea bed would generate local concentrations of 3×10^3 mg dm^{-3} at 100 m depths, but that local accumulations would be quickly dispersed to small concentrations. Based on short-term toxicological investigations of the chemical toxicity of natural gas he estimated that the likely range for plankton toxic effects would range from 50-500 mg dm^{-3}, and that, at sub-lethal concentrations, components of the hydrocarbons would be readily metabolized by microbes. As such, the biological impact on fishery resources of a gas sub-sea blowout would be confined to localized damage to plankton. Local marine conditions would probably strongly deter fishes from entering the immediate area. This would include the possible impacts associated with sulfurous materials which would probably also cause local avoidance of fishes and mammals. As such, Johnston

(1977) considered that no significant losses were likely to result from a gas blowout to fisheries in the North Sea.

5.3.6 Emissions to the Atmosphere

It is often overlooked that offshore blowouts will ultimately emit hydrocarbons to the atmosphere either directly, as with natural gas, or by evaporation or combustion of the hydrocarbons. Should fires occur, particulates, carbon oxides, nitrous oxides and, if sulfur is present, sulfurous oxides may all be released. Frazier et al. (1977) noted that the average composition of natural gas is primarily methane:

Methane (CH_4)	-72.3%
Ethane (C_2H_6)	-14.4%
Carbon Dioxide (CO_2)	- 0.5%
Nitrogen (N_2)	-12.8%

They summarized data showing the composition of emissions from blowouts of crude oil which are completely combusted (Table 5-22) and from a similar gas well (Table 5-23). In the case of a gas well blowout, obviously, if combustion is not occurring, the gas products would be released directly to the atmosphere minus any hydrates formed in the water. With inefficient combustion occurring emissions would consist of carbon dioxide, water, nitrogen and possibly sulfur dioxides.

5.3.7. Marine Mammals and Oil

The subject area of the effects of oil upon marine biota will be dealt with in detail in the environmental impact statement currently in preparation. A key concern arising from potential Arctic oil spills will be the effects on marine mammals. The literature on field experiences with oil and mammals is limited. Only one observation of marine mammals avoiding oil on the ocean was found in the literature. Loutif (1973) (p.159) noted that Brown (1971) stated that during the Santa Barbara Channel oil blowout offshore of California "the...incident occurred during the seasonal migration of the grey whale (*Eschrichtius glaucus* Cope), but it was observed that the whales took pains to avoid the oil. Five whales and four porpoises (*Phocaena* sp.) were found dead, a rather high mortality. Oil was not proved to be the cause, but the corpse of a bottle-nosed dolphin (*Tursiops truncatus* Montagu) had the blow-hole plugged with oil."

Damage to seals resulting from the Santa Barbara spillage was noted by the Smithsonian Institute (1969) and the California Department of Fish and Game (1969). Loutfi (1973) (p.163) cited other data suggesting that "evidence from California.....suggests that adult fish avoid areas of heavy oil contamination." This avoidance by fish may draw some mammals away from spills as they follow prey. Other

Table 5-22.

Estimated emissions from a burning crude oil blowout (Adapted from Frazier *et al*.(1977)).

	Emissions (kg/l oil)		
Pollutant	Fire *	Evaporation	Total
Particulates	2.85×10^{-3}	-	2.85×10^{-3}
SO_2**	5.42×10^{-2}	-	5.42×10^{-2}
Hydrocarbons	2.85×10^{-4}	38	1.09×10^{-1}
CO	2.59×10^{-3}	-	2.85×10^{-5}
Nitrogen Oxides	7.13×10^{-3}	-	7.13×10^{-3}

* Assumes burning to be the same as residual oil firing in industrial burners.

** Assumes sulfur 2.9%

Table 5-23.

Estimated emissions from a burning natural gas blowout (Adapted from Frazier *et al*. (1977)).

Pollutant	Emissions (kg $10^6 m^3$ burned)*
Particulates	304
SO_2**	0.6
CO	320
Hydrocarbons	128
Nitrogen oxides	1282

* Estimates from domestic combustion equipment

** Based on average sulfur content of 4.57 X 10^6 kg/$10^6 m^3$

evidence of impacts on marine mammals is cited in Loutfi (1973) (p.230) from the Santa Barbara experience. He noted that "Approximately 35 California sea lions were observed coated with oil but in no apparent distress. No increase in mortality of oiled elephant seals was reported. In most cases where mammal deaths were reported in the Santa Barbara area, the causes of death could not be positively established although oil contamination may have been a factor". Other data were cited (p.224) from the Torrey Canyon spill in the U.K. "Some seals were reported to be deliberately diving and surfacing through oil slicks. The mixture of oil and solvent-emulsifier was harmful to their eyes and tended to block their vital orifices. In addition, many of the seal caves used for breeding, etc., were contaminated. Approximately twelve badly oiled corpses were reported, and other seals were observed in difficulty." After the Chedabucto Bay spill in Canada harbour seals were found to be covered in oil more than 100 miles to the south on Sable Island where the oil affected vital orifices and gave rise to "considerable suffering and occasionally death by suffocation rather than by toxic effect" (Loutfi, 1973, p.239). While such damaging effects of oil on marine mammals have been noted from the Antarctic to the east coast of Canada, Loufti (1973) concluded that "...we know of no cases of extensive marine mammal mortality attributable to oil."

No instances of observations of sea birds avoiding oil slicks have been found and in some cases it has been suggested that the deceptive oil sheen of oil, especially around or on ice, may actually encourage the animals to land in it.

REFERENCES

Alaska Dept. Natural Resources. 1976. Oils Spills in Cook Inlet. Bulletin, Feb. 1976, Div. of Oil and Gas, Anchorage, Alaska, 1 p.

Allen, A. 1969. Santa Barbara Oil Spill. Statement presented to U.S. Senate Interior Committee Subcommitte on minerals, materials and fuels. May 20, 1969, 11 p.

Anon, 1970. Man's impact on the global environment - Assessment and recommendation for action. Rept. of study of critical environmental problems, M.I.T. Press.

Anon, 1974a. Final environmental statement - Proposed 1974 Outer Continental Shelf oil and gas general lease sales, offshore Texas. U.S. Dept. Int., Vol.I, F.E.S. 74-14.

Anon, 1974b. Final environmental statement - Proposed 1974 Outer Continental Shelf oil and gas general lease sale, offshore Louisiana. U.S. Dept. Int., Vol.I, F.E.S.-74-41.

Anon, 1975a. Assessing potential ocean pollutants. A report of the study panel on assessing potential ocean pollutants to the ocean affairs board commission on natural resources, N.R.C., National Academy of Sciences, Washington, U.S.A.

Anon, 1975b. U.S. Dept. Int., Draft environmental impact statement - Outer continental shelf, Northern Gulf of Alaska.

Anon, 1978. Tanner Bank mud and cuttings study. Ms. Rept., Shell Oil Co., Houston, Texas. Executive Summary, 40 p.

Baker, R. 1978. A study of environmental concerns offshore oil and gas drilling and production. Fisheries and Environment Canada. Ms. Rept. EPS-2-EC-78-1, 112 p.

Bercha, F.G. 1977. Determination of probabilities of oil spills in Canadian Arctic waters. Unpublished Rept. for Fisheries and Environment Canada.

Bisset, R. 1978. Quantification, decision-making and environmental impact assessment in the United Kingdom. J. Environ. Management (7), 43-58.

Brooks, J.M., Bernard, B.B., Sauer, T.C., and Abdel-Reheim, H. 1978. Environmental aspects of a well blowout in the Gulf of Mexico. Environ. Sci. Technol., 12(6): 695-703

Brown, T. 1971. Oil on ice. Alaskan Wilderness at the Crossroads. R. Pollack (ed.) Sierra Club, San Francisco and New York.

Bruce, H.E. 1976. A study plan for the Alaska continental shelf. In: Assessment of the Arctic marine environment. Hood, D. and Burrell, D. (Eds.), Inst. of Marine Science, Univ. Alaska, p.61-80.

California Dept. Fish and Game. 1969. Santa Barbara oil leak. Interim. Rep. Calif. Dept. Fish and Game (Dec.15).

Canadian Arctic Resources Committee. 1978. Northern Perspectives, Offshore drilling in Lancaster Sound, Vol.6, No.6, 12 p.

Carter, E.E. 1972. What are the risks in risk analysis? Harvard Business Review, July-August, 72-82.

Danenberger, E.P. 1976. Oil spills, 1971-1975 Gulf of Mexico Outer Continental Shelf. U.S. Geol. Survey , Circular 741, Washington, 47 pp.

DIAND (1977). Beaufort Sea authorized press release, June 1, 1977. Ottawa, Ontario.

DIAND (1978). Personal Communication M. El-Defrawy, Chief DIAND Oil and Gas Eng. Div., to D. Marshall, F.E.A.R.O., Dec. 1978.

Elkins, H.L. 1976. Annular blowout preventers, Ram-type blowout preventers, Choke/Kill valves and Unitized blowout preventers. In: The technology of offshore drilling, completion and production. Petroleum Pub. Co., Tulsa. p.258-300.

Energy, Mines and Resources Canada, personal communication. Letter from G.R. Yungblut, Director, Operations and Conservation Division, Ottawa, Ontario, Sept. 1978.

Energy, Mines and Resources Canada, personal communication Letter from G.R. Yungblut, Director, Operations and Conservation Division, Ottawa, Ontario, Nov. 1978.

Energy, Mines and Resources Canada, 1977. Offshore Exploration, Information and procedures for offshore operators, 6th Issue, 84 p.

Federal Assessment and Review Office (F.E.A.R.O.), 1978. Transcripts of public hearings at Frobisher Bay, N.W.T. Testimony of Dr. R. Skinner, Energy, Mines and Resources Canada. Hearing into Davis Strait drilling application.

Fisheries and Environmental Canada, 1978. Potential Pacific Coast oil ports: A comparative environmental risk analysis. Vol.I, Vancouver, 98 pp.

Foster, M., Charters, A., and Neushul, M. 1969. The Santa Barbara oil spill. I. Initial quantities and distribution of pollutant crude oil. In: Santa Barbara oil pollution, 1969. Federal Water Quality Administration, U.S. Dept. of the Int.

Frazier, N.A., Maase, D.L. and Clark, R. 1977. Offshore oil and gas extraction-an environmental review. Industrial Environ. Res. Lab., U.S.E.P.A., Cincinnatti, Ohio, U.S.A. Ms. Rept., 59 p.

Goodwin, R.J. 1972. Control of formation fluids at geostatic pressures during drilling operations. Proc. Northern Canada Offshore Drilling Conf., Dec. 5-6, 1972. D.I.A.N.D.

Haefeli, E.T. 1973. Representative government and environmental management. Baltimore: Resources for the future, Inc. The Johns Hopkins Univ. Press, pp. 1-188.

Hall, W.K. 1975. Why risk analysis isn't working. Long-Range Planning, Dec. 1975: 25-29.

Harrald, J.R., Boyd, B.D. and Bates, C. 1977. Oil spills in the Alaskan coastal zone the statistical picture. In: Fate and effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms, Ed. D. Wolfe. Pergamon Press, Toronto, 478 p.

Imperial Oil Ltd., Aquitane Co. of Canada Ltd. and Canada-Cities Service, Ltd. 1978. Environmental Impact Statement for Exploratory Drilling in Davis Strait Region.

Johnston, R. 1977. What North Sea oil might cost fisheries Rapp. P.-V. Reun. Cons. Int. Explor. Mer, 171-212-223.

Kash, D.K. et al. 1973. Energy under the oceans - A technology assessment of the outer continental shelf oil and gas operations. Univ. Oklahoma Press.

Kates, R.W. 1977. Assessing the assessors: The art and ideology of risk assessment. Ambio (6): 5, 274-252.

Kennedy, J.L. 1971. Losing control while drilling: a 32-well look at causes and results. Oil and gas J., September: 121-126.

Loutfi, M. 1973. Canadian Maritime Oil Exploration, Exploitation and Transport: A Multidisciplinary Study. Office Industrial Res., McGill University, 364 p.

MacKay, D. and Wilks, A. 1978. A statistical analysis of oil spills in Canada. Univ. of Toronto/ York Univ. Joint Program in Transportation, Research Report No. 50, 61 pp.

Megill, R.E. 1977. An introduction to risk analysis. Petroleum Publishing Co., Tulsa, Okla. 199 p.

Milne, A.R. and Smiley, B.D. 1976. Offshore drilling for oil in the Beaufort Sea: A preliminary environmental assessment. Tech. Rept. No. 39, Beaufort Sea Project, 43 p.

Milne, A.R. and Smiley, B.D. 1978. Offshore drilling in Lancaster Sound: Possible environmental hazards. inst. Ocean Sci., Patricia Bay, B.C., 95 p.

M.I.T. 1973. The St. Georges Bank Petroleum study. Vol.II. Rept. No. MITS G 73-5, Feb.1973.

Norlands Petroleums Ltd., 1978. Environmental Impact Statement for Exploratory Drilling in the Lancaster Sound Region.

Paproski, D.M. 1977. Weighing conflicting concerns in the context of frontier development. Economic Council of Canada, Rept. No. 96, Ottawa. 218 pp.

Ray, J.P. 1978. Drilling mud toxicity: Labratory and real world tests. Ocean Resources Eng. April, 8-12.

Reifel, M.D. 1976. Offshore blowouts and fires. In: The technology of offshore drilling, completion and production. Petroleum Pub. Co., Tulsa. p. 239-257.

Sanborn, H.R. 1977. Effects of petroleum on ecosystems. In: Effects of Petroleum on Arctic and Subarctic Marine Environments and Organisms. Vol. II. Biological Effects. D.C. Malins (Ed.). p. 337-357.

Sondheim, M.W. 1978. A comprehensive methodology for assessing environmental impact. J. Environ. Management (6) 27-42.

Smithsonian Institution, 1969. Center for short-lived phenomena event information reports, 9-69 (1 to 39). Cambridge, Mass.

State of Alaska, personal communication. Letter from Dept. Nat. Resources, Oil and Gas Conservation Division, L. Smith, Chief Petroleum Engineer, Anchorage, Alaska.

Trost, W.R. 1976. Citizen participation and environmental conservation. Proc. Manitoba Environmental Res. Council, Oct., Winnipeg, Manitoba.

6.0 SOCIO-ECONOMIC IMPACT

6.1 TOWARDS A SOCIO-ECONOMIC IMPACT STATEMENT

A Socio-Economic Impact Statement will be prepared. Its inclusion in the Environmental Impact Statement signifies that to the Proponent the environmental, social and cultural issues arising from the proposal are inextricably interwoven.

The Proponent intends to proceed carefully in the formulation of this socio-economic impact statement simply because it is impossible to know a priori what will be of major concern to the community. The social impact of our activities will be a function of the values of the people in the community. Time is required for the proponent and the community to explore with each other through Petro-Canada's community involvement program areas of coincidence and difference of values. Only then can a statement of impact, which is relevant to the decisions which have to be made, be prepared.

However, in the view of the Proponent the potential socio-economic impact of the proposed activities follow from two realities. Firstly, there is a potential for a blowout from an exploratory well and secondly, the proponent requires a shore base from which to operate. The question of the possibility of a blowout and the possible effects which it might have on the marine and terrestrial environments has been dealt with elsewhere in this report. The Proponent recognizes the potential such an event has to be socially disruptive and will address this issue once environmental hazards are better defined. The anticipated socio-economic impact of shore-based activities will be small in comparison to that of land based oil and gas exploration or of the drilling in the Beaufort Sea by a dedicated fleet of drillships or of year around activities such as mining.

The reader is referred to Appendix #2 for a preliminary table of contents for the socio-economic impact statement.

6.2 DEVELOPMENT AND THE INUIT

For several reasons the proposal and what may follow is of singular importance to the people of Northern Baffin Island. The Inuit live in small communities and are in the main untouched by and unfamiliar with developers and

development. Their way of life and their culture are closely linked with the land and sea. A perceived or real danger of environmental impact becomes a threat to their way of life and their culture. Hunting and fishing still provide much of their food. The aboriginal rights of the Inuit, under negotiations toward a settlement of claims, strengthen their views. As a result they are opposed to development and representations at hearing on exploration proposals for Lancaster Sound and Davis Strait bear witness to this.

6.3 DEVELOPMENT AND THE GOVERNMENT

On the other hand, the Government of Canada favours "controlled" development of the north; development with impacts within acceptable limits.

6.4 COMMUNITY INVOLVEMENT

In order to minimize the adverse socio-economic impacts and maximize potential benefits of Petro-Canada's Baffin Bay exploratory drilling program it is the intention of Petro-Canada to carry out an active program of community consultation. Before elaborating on this ongoing and proposed consultation program the Proponent wishes to take this opportunity to explain its philosphy with respect to community consultation and involvement.

Public participation, public involvement, community consultation, community involvement, community liaison, are all expressions which are used daily by many of us. Their currency implies a degree of concensus on the meaning of these terms which does not in fact exist. In order that there be no misunderstanding either at community level or in government the Proponents understanding of these terms is hereby offered for consideration.

The term "community involvement" shall be used here to refer collectively to all those expressions which imply a degree of community or public involvement in decision-making. For analytical purposes we can distinguish a continuum along which are arranged several different "types" or "degrees" of community involvement. With each type of involvement there are associated roles for the community, the government and the proponent.

The lowest level or degree of involvement may be characterised as a "persuasion" model. In this model the role of the public or community is restricted to that of a passive participant. The government or the proponent take the initiative, make the decisions, implement the plans, and

evaluate the success of the project. The public essentially receives an advertising message.

At the other extreme rests the "self-determination" model. In this model the public initiates projects, makes the decisions, implements decisions and evaluates the success of the project.

The proponent believes that in order for its activities to take place in a context which assures the general public that the best possible project is developed that an explicit model of community involvement must be articulated which describes the respective roles of the government, the community and the proponent.

The proponents view of these roles may be illustrated diagrammatically (Fig. 6-1).

A number of observations must be made with respect to the above model in order that the implications of the various roles be clear. Firstly, it is assumed that the community involvement program takes place with respect to a proposed set of activities to be undertaken by the company, including mitigation and enhancement activities. Secondly, it will be noted that some roles are shared by the three parties to the process while others are the sole responsibility of one party or another. Of critical importance in our view is the fact that it is the government which is the decision-maker. It is assumed by the proponent that a key factor in the goverments decision making will be the degree to which the community and the proponent can agree on an acceptable social action plan. Nevertheless, it is recognized that there will be differences of opinion on the part of the community and the proponent. These differences will follow from fundamental differences in value orientations held by the two non-governmental parties to the process. It is precisely because such differences of opinion are anticipated that a community involvement process is required and a third party, in this case government, is required to make the ultimate decisions.

It will, therefore, be a prime objective of the proponent to identify through its community involvement program substantive areas of agreement and disagreement between the community and the proponent. The proponent recognizes its responsibility to do the basic environmental and social research which will allow the community and government to evaluate the impact of the proponents proposed activities. The proponent also recognizes its obligation to negotiate with the government and the community jointly acceptable

AN INFORMATION-FEEDBACK MODEL

OF COMMUNITY INVOLVEMENT

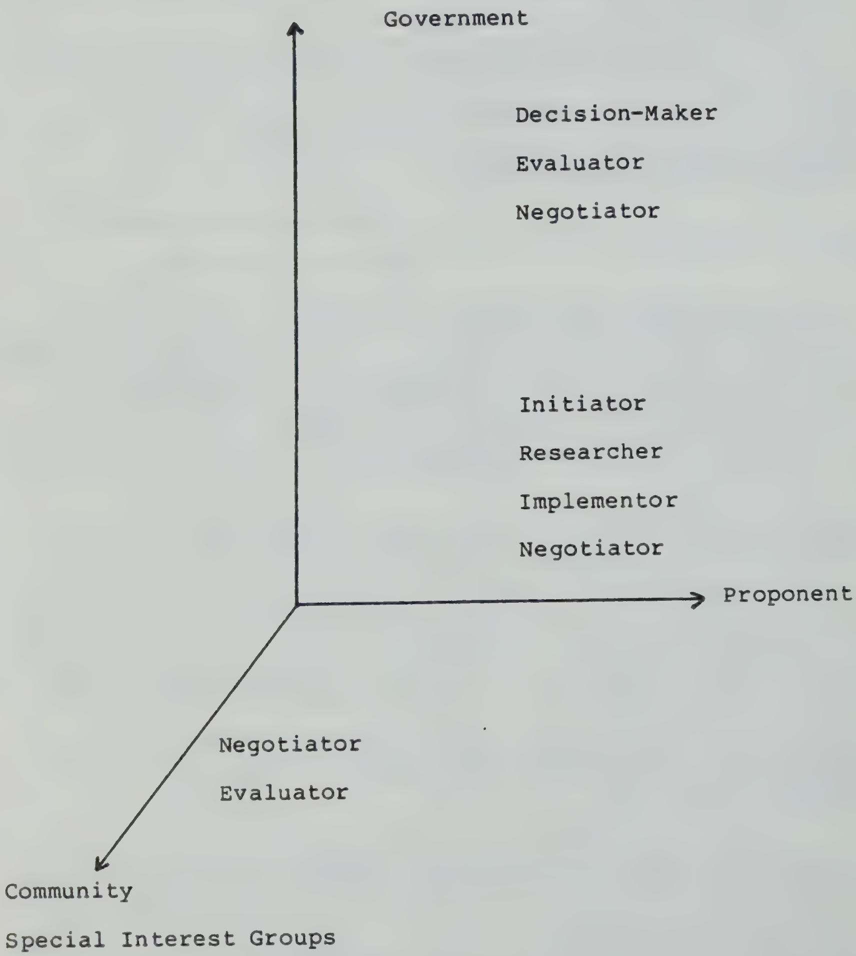


FIGURE 6-1. ROLES OF PARTICIPANTS

solutions to adverse impacts and action plans to capitalize on potential benefits.

6.5 POLICY

The proponent has developed a socio-economic policy for the proposed operation, the details of which are noted below.

6.5.1. Community Involvement

Petro-Canada will initiate and/or participate in a community involvement program to allow a free exchange of information, suggestions, concerns and comments between the corporation, affected communities and residents, local and regional interest groups and government agencies related to environmental studies, operational plans and socio-economic plans and performances. The Proponents' basic view of this involvement program was elaborated above. The basic objectives of the involvement program will be:

(a) to advise and inform the community on our current and proposed activities.

(b) to seek the advice and comment of the community with respect to our activities.

(c) to negotiate the details of a social action program including the use of local services, a northern employment policy, and the general operational procedures for Petro-Canada's staff in Pond Inlet and the region.

As noted earlier where agreement cannot be reached between the proponent and the community these differences will be referred to the government for decision.

6.5.2. Use of Local Services

Petro-Canada will procure goods and services from northern enterprise if offered at reasonably competitive prices and if the supply to local residents is not affected. In order to improve the competitive position of northern business, Petro-Canada will arrange for early procurement where practically possible.

6.5.3. Northern Employment

Petro-Canada will give preference to northerners in recruitment and will identify job opportunities and skills early to allow maximum training. Because of the seasonal and

possibly short term nature of the project, emphasis will be placed on those skills that are transferable to permanent northern activities.

6.5.4. Social and Cultural Considerations

Petro-Canada, in consultation with governments, communities and special interest groups, will take measures to lessen to the greatest practical extent, the impact of the operation on the social and cultural fabric of the communities and the region.

6.5.5. Infrastructures

Petro-Canada will avoid overtaxing of communication, transportation, health and government services now in place and develop independent structures dedicated to the operation, where required.

6.6 THE SOCIO-ECONOMIC PROGRAM BEFORE DRILLING

Success of socio-economic measures depend largely on their integration into the operational plan and into the operation. Several initiatives were and will be taken in the predrilling period to make this integration feasible. However, where the proponent faces large expenditures, such as in training and recruitment programs and, in business development programs, program initiation must await environmental clearance and completion of operational feasibility studies. Paradoxically these socio economic thrusts require a long lead time to be successful, while decisions on environmental clearance, and indeed feasibility, are traditionally made at the eleventh hour.

The Proponent has embarked on a deliberate program of involvement with people in the region, and particularly Pond Inlet, during the pre-drilling period. For example, goods and services have been obtained locally where practical, Hunters and Trappers Associations are involved in harvest surveys, councils and the public were made aware of study plans through meetings, over-flights and through radio and newspaper. The Proponent's participation as a member of the EAMES Advisory Board ensures regional awareness of studies.

Discussions of the proponent's plans for a shore base at Pond Inlet have been initiated with the Council of Pond Inlet. The plans for the base are of importance to the two parties alike and the determination of their fate is cri-

tical to operational planning and to social and economic impact.

In addition to continuing these initiatives, the proponent will start a more formal impact awareness program with the objective of conveying factual information on the proponent's operational plan to the public of the Northern Baffin Region.

Logistics during the 1978 field studies and again in 1979 will be coordinated by the Proponent's operational personnel. This allows an early and practical assessment of the regional infrastructure, local business acumen and local work attitudes and will lead to integration of practical mitigation and enhancement measures in the operational plan.

The pre-drilling activities including the EAMES Program in Pond Inlet has resulted in an influx of people, aircraft etc. which may have more impact than that of a well-ordered and planned drilling operation. During the pre-drilling phase the Proponent's operational personnel are guided by the socio-economic policy stated above.

6.7 HISTORIC RESOURCE USE

For the purposes of this preliminary assessment only Pond Inlet (Mittimatalik) is considered in detail.

Exploration and resource exploitation are not recent developments on N.E. Baffin Island. There is an extensive history of European exploration in the region of Lancaster Sound, the earliest of which was related to the search for a Northwest Passage. The entrance to Lancaster Sound was discovered in 1616 by Robert Bylot. In 1818 John Ross named Pond Inlet "Pond's Bay" in honour of the British Astronomer Royal and in 1820 W. Parry sailed into Pond Inlet, discovering and naming Navy Board Inlet in the process. Leopold McClintock passed by in 1858 searching for the Franklin Expedition and in the mid-1850's the whaler Eclipse discovered the Sound named for it. Throughout this period of history whalers made many discoveries but kept them secret for purposes of commercial advantage. As a result of this secrecy it was not until 1872 that another British whaler, William Adams demonstrated the insularity of the Island named after Robert Bylot (Lamont, 1978).

From 1880 to 1900 whalers and free traders frequented Albert Harbour, which is about 17 miles east of the present settlement of Pond Inlet. By 1903 a permanent whaling station and a trading post were established there. In

1903 a whaling expedition from Dundee, Scotland led to the first anthropological paper being written about the people of "Pond's Bay" in association with those whaling activities (Mutch, 1906).

In 1901 Robert Janes, a mate on a whaler, discovered what he thought was gold near Albert Harbour and a flurry of prospecting resulted in the subsequent year. The discovery proved to be false; however, this event probably resulted in the Geological Survey dispatching a scientist, A.P. Low, and Capt. Joseph-Elzear Bernier to the region between 1903 and 1911 to survey the area and assert Canadian sovereignty in the region.

Robert Janes returned after World War I as a trader, however, in 1921 he was murdered at Pond Inlet. This event led to the establishment of an R.C.M.P. post there in 1922 (then called Pond's Inlet). The Hudson's Bay Company established a post there in 1921 and in 1926 Missions were founded there by Catholic and Anglican Missionaries.

Lamont (1978) noted that there was no year-round Inuit settlement at the present site of Pond Inlet in the late 1920's as the people preferred to use the site (then called Mitimatalik) as a summering location. In May and June the Inuit traditionally gathered at Button Point (Sannirut) (at the S.E. tip of Bylot Island) from which Bearded Seal and Narwhal were hunted after which time, when the ice was badly broken up, the move would be made to Mitimatalik (literally "the place of the grave of Mittima").

In 1956 the settlement held only 41 people. The bulk of the regions population of 170 preferred to live in scattered camps on the land. However, with the opening of a small school in 1960 (the larger school was built in 1966) and a nursing station at about the same time, coupled with a governmental housing program, the settlement grew rapidly. Today Pond Inlet has a population of about 600 and the economy of the community will be elaborated more fully in the socio-economic impact statement.

6.8 PATTERNS OF HARVEST

Freeman (1976) conducted an extensive research project to define the extent and type of Inuit land use throughout the Arctic. His study indicated a considerable reliance by Inuit of north Baffin Inland on the marine environment chiefly for narwhal, ringed seal and polar bear. Data provided by Fisheries and Marine Service (pers. comm.) (Tables

6-1 and 6-2) confirm the importance of narwhal and ringed seal to the resource-based economy of Pond Inlet. Polar bear are also killed by the residents at annual quota levels of about 13. Arctic fox are trapped throughout the Pond Inlet area from Eclipse Sound to Navy Board Inlet.

Arctic Char are caught at river outlets throughout the Pond - Navy Board Inlets at rates which are rather less than is known for other settlements such as Arctic Bay, Frobisher Bay and Pangnirtung (Table 6-2).

Thick-billed Murres and Greater Snow Geese are taken by local residents where occasions permit.

6.9 AREAS OF SPECIAL INTEREST

The International Biological Program (I.B.P.) has identified seven sites in the Lancaster Sound region (Fig.6-2). The I.B.P. recognized Lancaster Sound as an exceptional region in the High Arctic as it supports populations of animals which are recognized as being of international importance. In addition, Parks Canada have identified several areas in the region as natural areas of Canadian significance (NACS) and natural sites of Canadian significance (NSCS) (Fig. 6-3, 6-4 and 6-5). Parks Canada have in preparation a regional analysis of the Eastern Arctic Marine Region particularly at the eastern end of Lancaster Sound. In addition, Parks Canada have suggested "the entire Sound and adjacent coastal reaches as a candidate for submission to the World Heritage List" (Parks Canada, 1978). Parks Canada based this decision on the fact that "two NACS, one NSCS and two candidate NACS were identified and when taken together encompassed a considerable portion of the coastal and marine elements of the Sound itself."

In addition, the Canadian Wildlife Service has designated several "critical wildlife areas" in the region (Fig. 6-7) including the sanctuary of Bylot Island (Fig. 6-8). The more recent Arctic Marine Oil Spill Program (AMOP) also listed specific areas of hunting and trapping in their Arctic Atlas (Fig. 6-9).

The entire region has had several proposed ecological sites from the International Biological Program (I.B.P.) many of which lie within, or near to, Lancaster Sound (Fig. 6-10).

Table 6-1.

Marine Mammal Harvest (Fisheries and Marine Service, personal communication)

Location		Cetaceans		Pinnipeds			
	1975	Beluga	Narwhal	Walrus	Harp	Ringed	Other
Arctic Bay		-	167	-	19	1,773	1
Grise Fiord		10	-	20	142	688	1
Resolute Bay		11	-	-	-	109	78
Pond Inlet		-	77	-	6	1,627	1
	1976						
Arctic Bay		-	115	-	4	1,161	46
Grise Fiord		15	11	23	109	598	-
Resolute Bay		11	-	3	1	243	3
Pond Inlet		-	125	6	48	1,674	8
	1977						
Arctic Bay		-	40	1	(DATA INCOMPLETE)		
Grise Fiord		11	-	3	(DATA INCOMPLETE)		
Resolute Bay		17	2	2	(DATA INCOMPLETE)		
Pond Inlet		-	99	6	(DATA INCOMPLETE)		

Table 6-2.

Estimated fisheries resource use on Baffin Island (Fisheries and Marine Service, personal communication).

Location	Arctic Char (kg)
Frobisher Bay (Nettelling Lake)	11,338 - 27,223*
Pangnirtung	4,537 - 13,612*
Broughton Island	1,360 - 3,630**
Clyde	907 - 2,722**
Cape Dorset	907 - 2,270**
Lake Harbour	907 - 2,270**
Pond Inlet	1,360 - 3,630**
Arctic Bay	6,800 - 9,075**
Igloolik and Hall Beach	9,075 - 13,600*

* Commercial Harvest
** Commercial and Domestic Harvest

INTERNATIONAL BIOLOGICAL PROGRAMME SITES

Figure 6-2

PARKS CANADA – NATURAL AREAS AND SITES OF CANADIAN SIGNIFICANCE

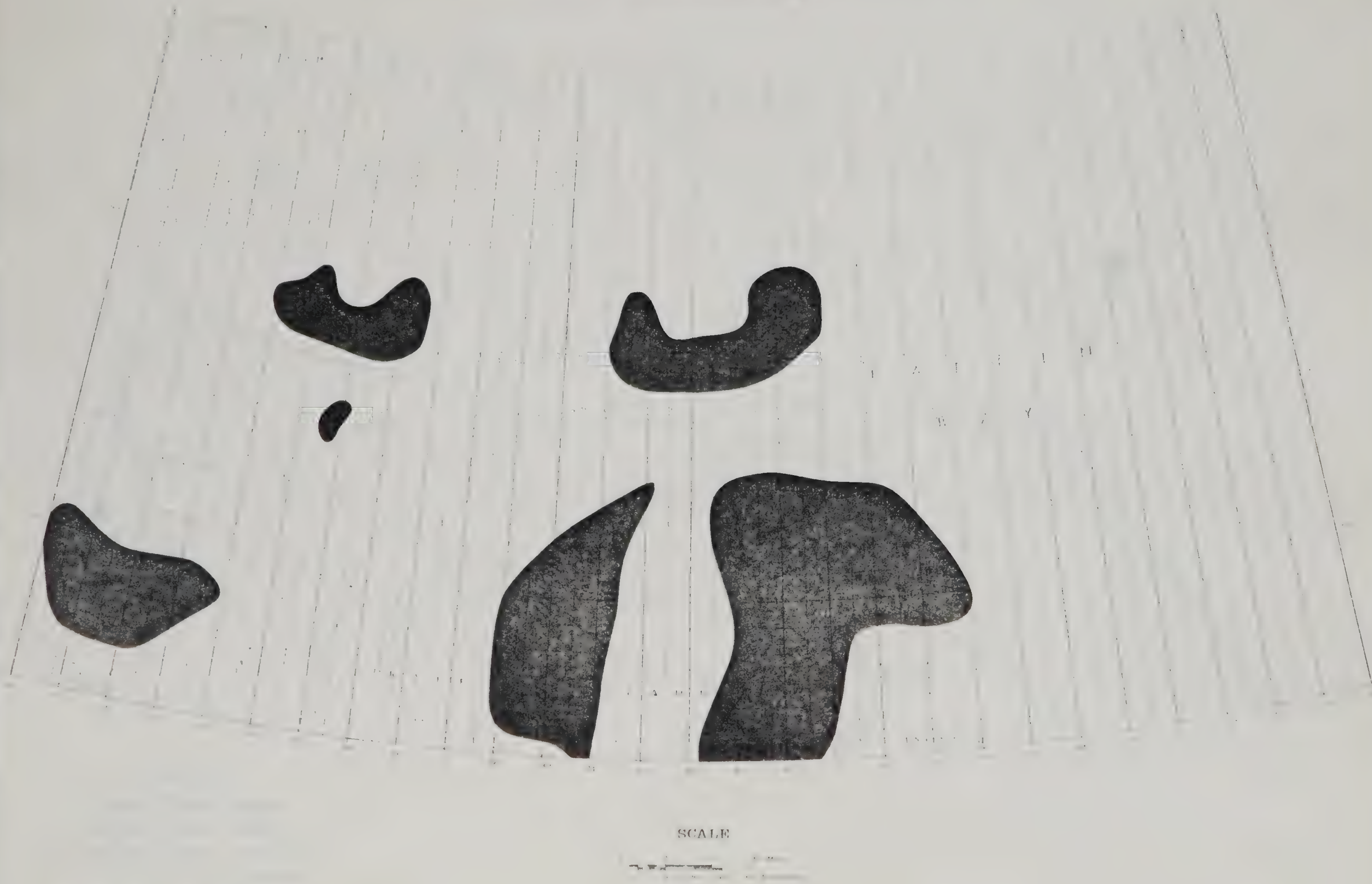


Figure 6-3

NATIONAL PARK NATURAL REGIONS

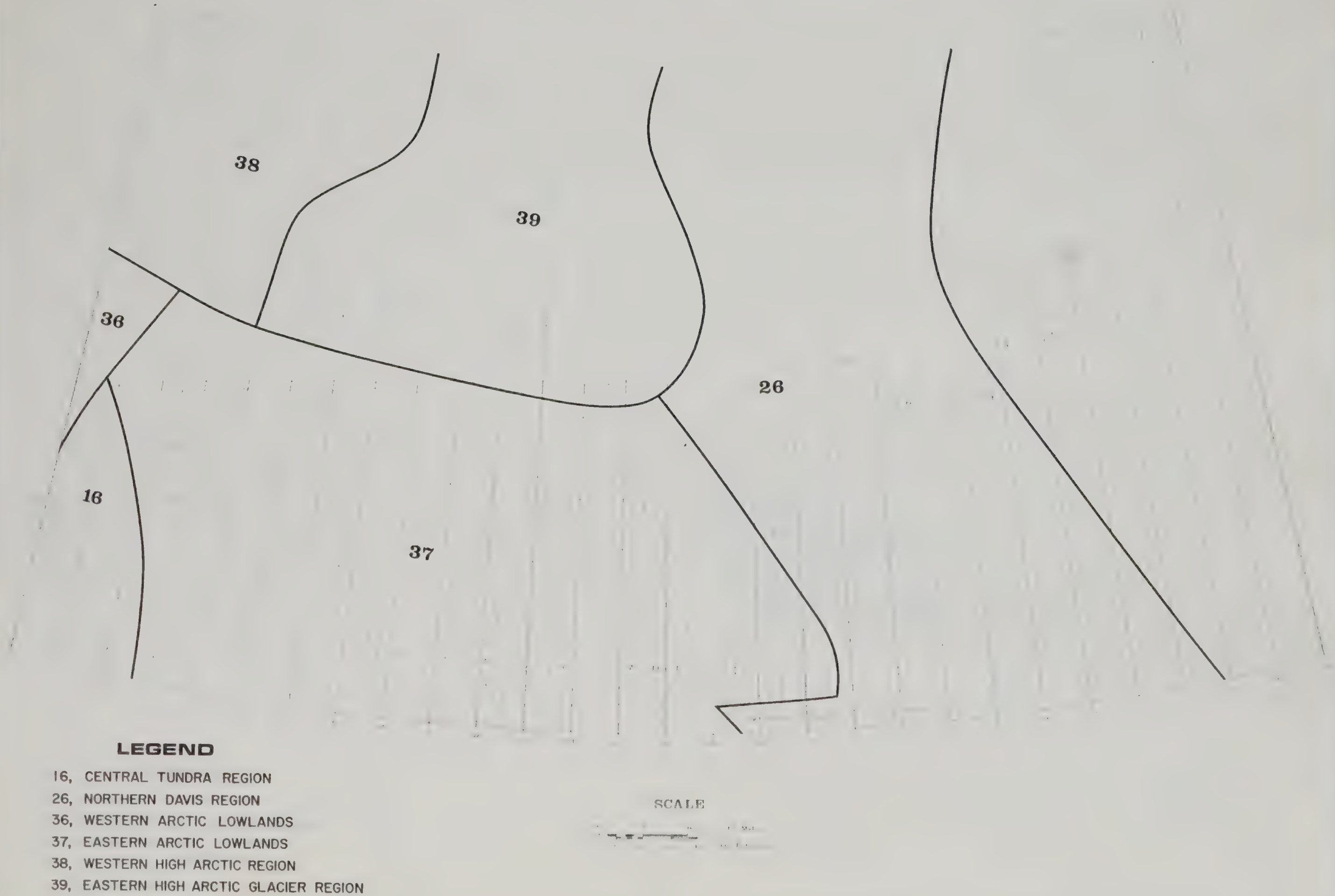


Figure 6-4

NATIONAL PARK MARINE - NATURAL REGIONS

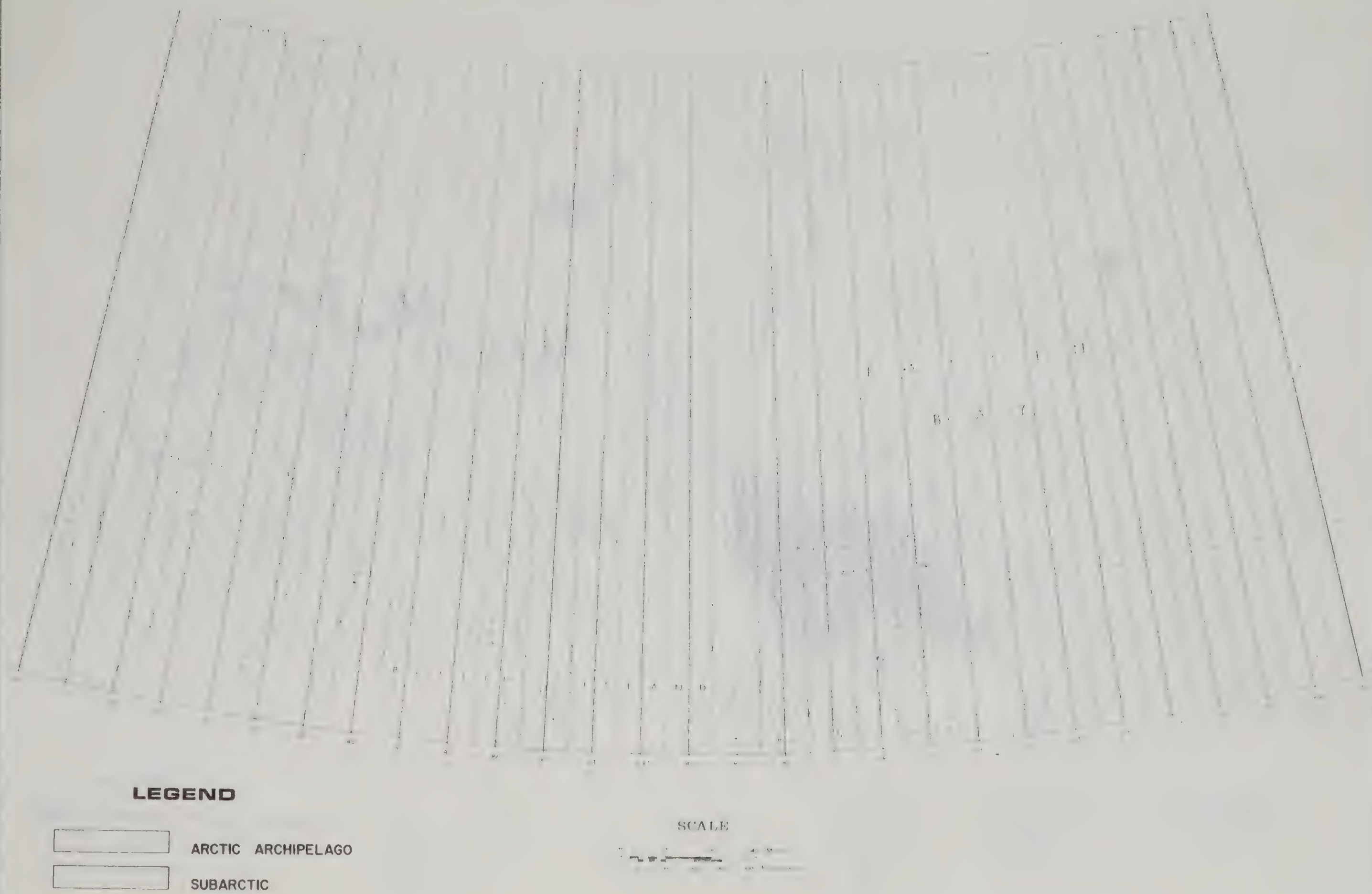
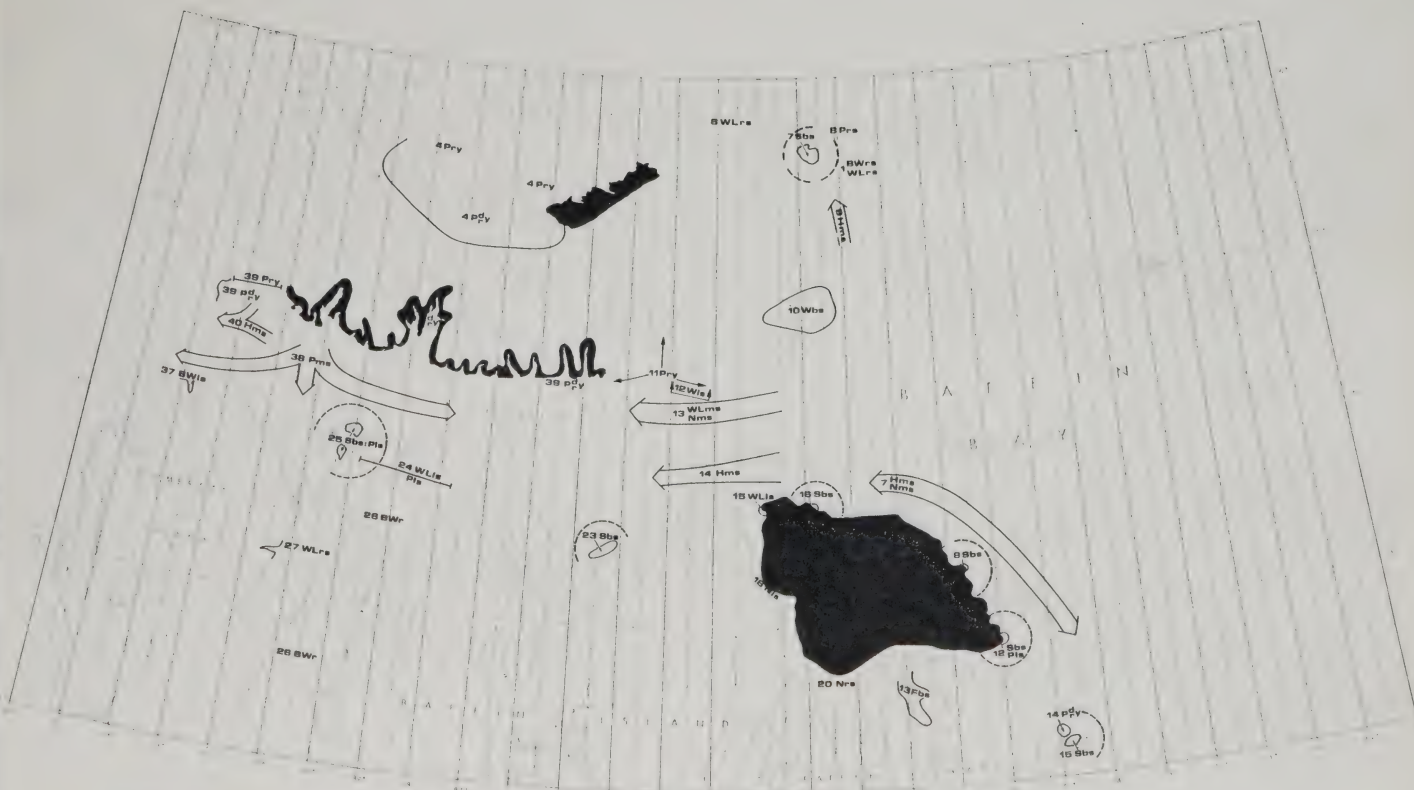


Figure 6-5

CRITICAL WILDLIFE AREAS



LEGEND

CRITICAL WILDLIFE AREA

IMPORTANT WILDLIFE AREA

MIGRATORY ROUTE

EXAMPLE: (1 Wbs)

Unit Description (Number) 1

Species (Waterfowl) .... W

Habitat Function (Breeding) .... b

Seasonal Use (Summer Only) .... s

SCALE

10 0 20 40 Miles

0 20 40 60 Kilometres

Key to Species

- P – Polar Bear
- BW – Beluga Whale
- H – Harp Seal
- N – Narwhal
- WL – Walrus
- S – Seabirds
- W – Waterfowl
- F – Anadromous Fishes
- X – Muskoxen

Key to Habitat Function

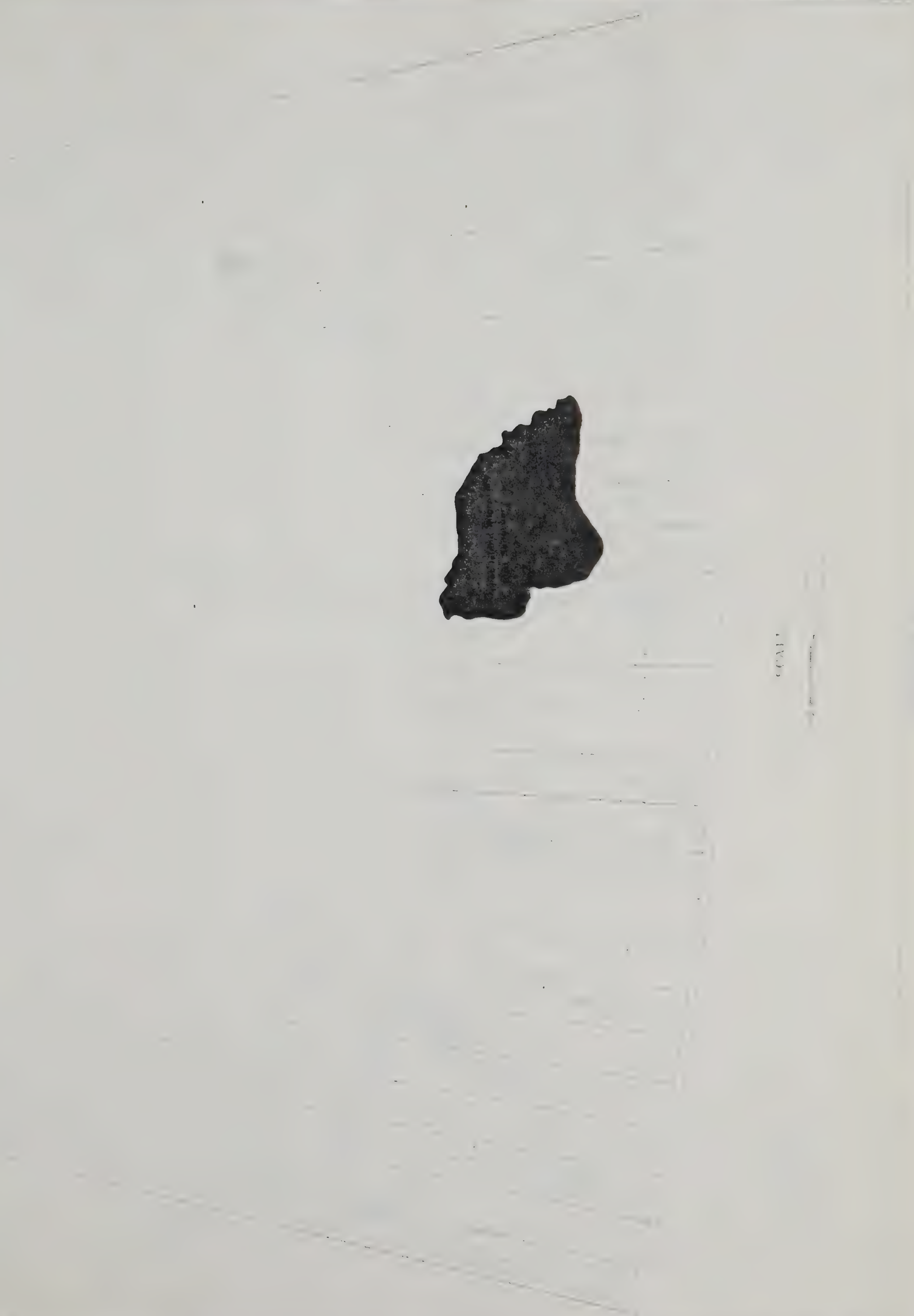
- b – Breeding Area
- d – Denning Area
- l – Staging Area
- r – Range
- m – Migratory Route

Key to Seasonal Utilization

- s – Summer Only
- y – Year Round

Figure 6.7

Petro-Canada



SANCTUARIES

Figure 6-8

HUNTING AND TRAPPING

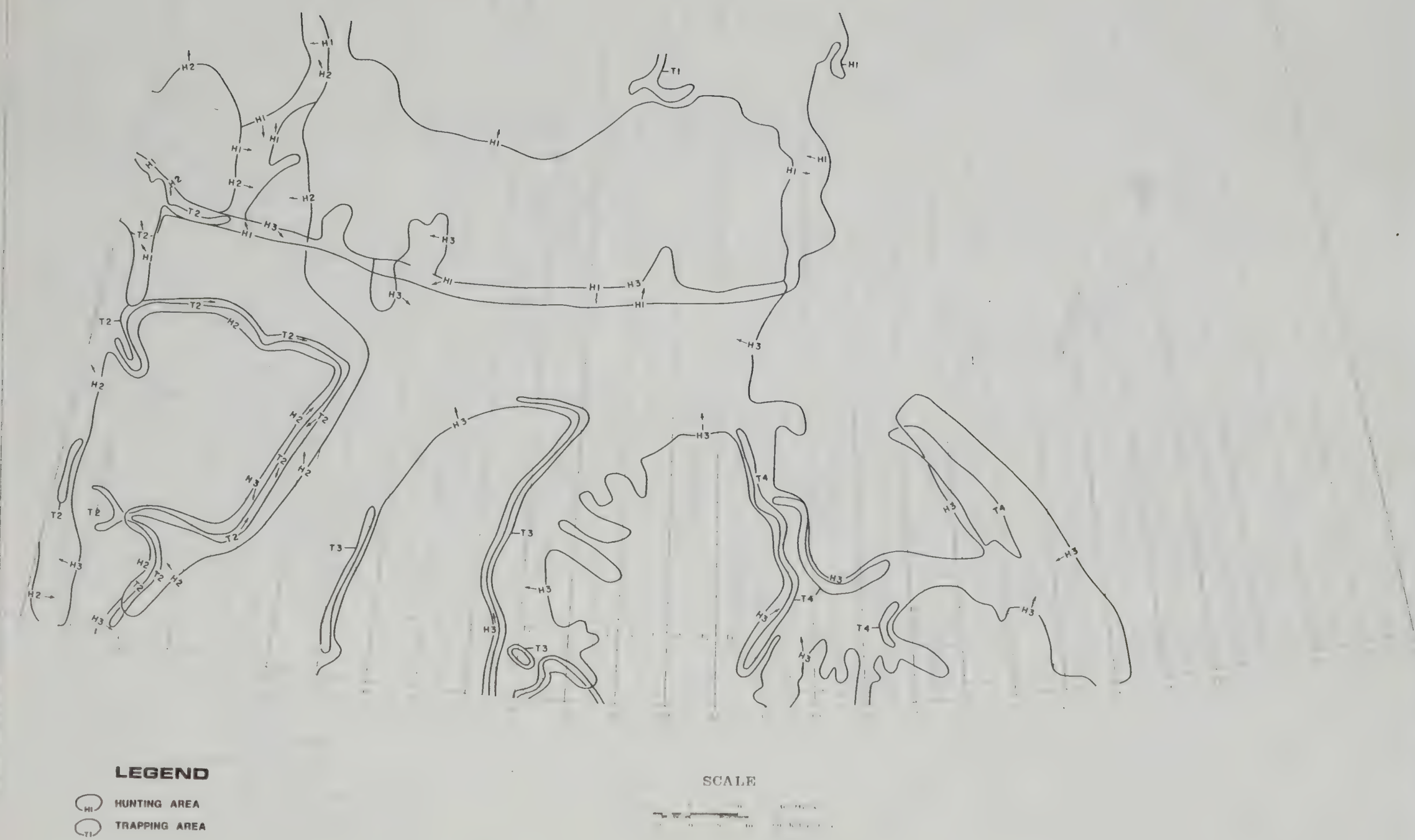


Figure 6-9

PROPOSED ECOLOGICAL SITES

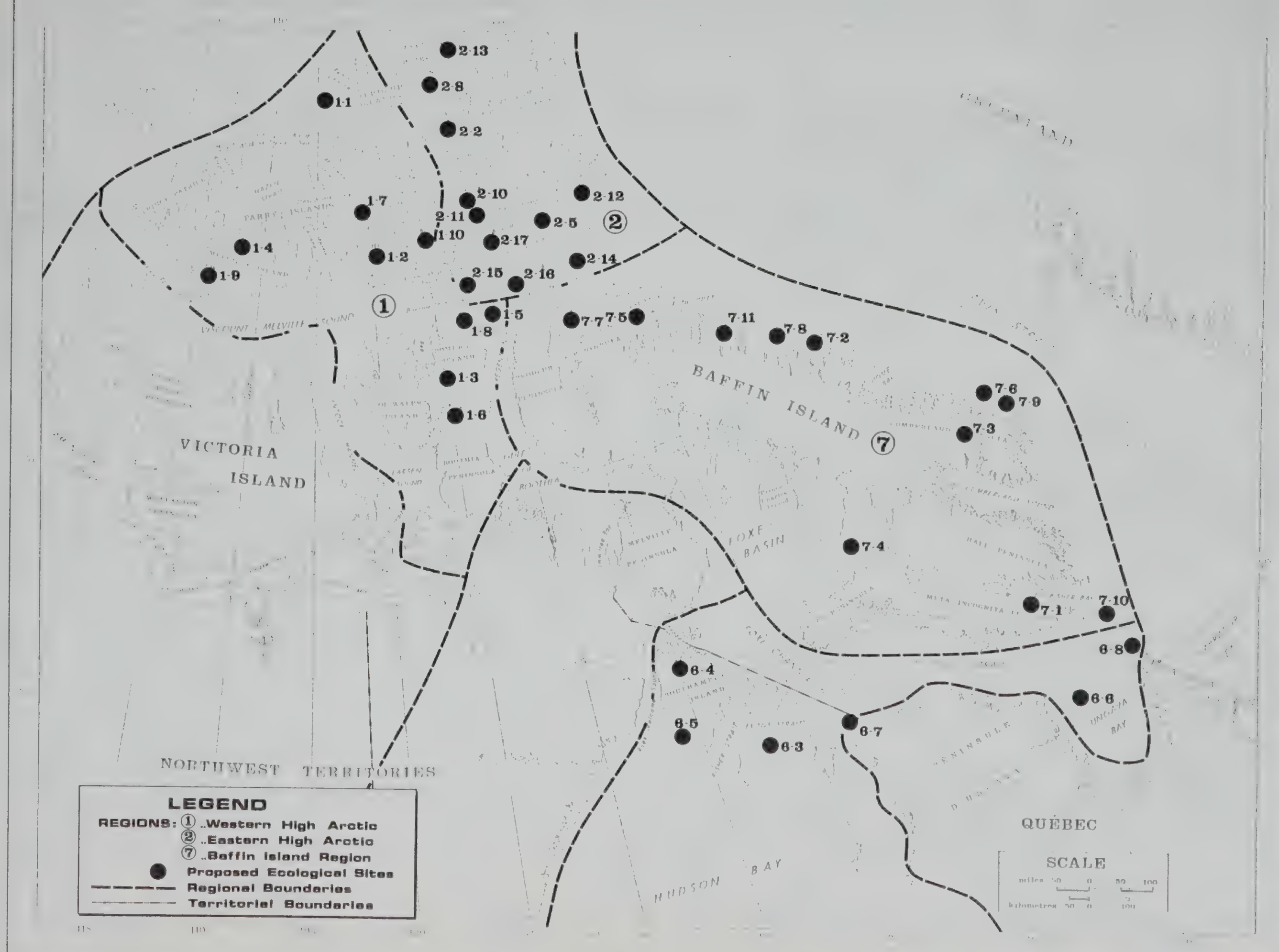


Figure 6-10

REFERENCES

Fisheries and Marine Service, Personal communication. Letter from B. Wong, Yellowknife, N.W.T. Oct., 1978.

Freeman, M.R. 1976. Inuit land use and occupancy project. Vol. I. Land-use and occupancy. DIAND, Ottawa. 263 p.

Lamont, J. 1978. Trekking across Bylot Island. Can. Geographic (97): 2, 52-59.

Mutch, J.S. (Capt.). 1906. Whaling in Pond's Bay. In: Anthropological Papers: Boas Anniversary Volume. Stechert and Co., New York, p. 485-500.

Parks Canada, 1978. Parks Canada's Interests in Lancaster Sound. A brief presented to the Lancaster Sound Environmental Assessment Panel, Pond Inlet, N.W.T. November, 22 p.

7.0 OIL SPILL CONTINGENCY PLANNING

7.1 INTRODUCTION

Petro-Canada has under review extensive plans for countermeasures against the spillage of hazardous substances, including petroleum hydrocarbons, in or near Baffin Bay. Part of that planning effort includes an active participation in the newly-formed East Coast Oil Spill Co-operative.

As a standard code of practise, there will be interlocking measures established to anticipate and prevent the accidental loss of any chemicals or petroleum products as a result of the drilling process. Nevertheless, Petro-Canada acknowledges that even when exceptional standards of practise are maintained, accidents may occur. Therefore, measures for the recovery, containment or dispersal of compounds which may be accidentally lost are being developed by the Proponent.

A detailed Contingency Plan is being drawn up at the time of this writing and will be presented to Government regulatory bodies as is required.

The initial assessment contained herein deals with a preliminary review of the fate of oil in the Arctic marine environment. The consideration is based on regional, rather than site-specific instances, and will be more fully developed in future submissions. The latter will include detailed modelling of oil slick trajectories from potential drilling sites at various times of the year. These studies await results from oceanographic research done during the 1978 field season which it is anticipated will provide significant new insights into details of current regimes in Lancaster Sound.

There are two principal routes for the potential entry of oil, or other chemicals, into the Arctic marine environment of Lancaster Sound:

(a) Release from a vessel lost at sea
(b) An uncontrolled flow from the a drilling well.

Losses of fuel oil may occur during transfer operations, but such losses are presumed to be of a lower order of magnitude than the former potential sources. It is anticipated that contingency plans in place by the time of

commencement of operations will be adequate to contain or limit the spread of oil into the environment.

Detailed studies of blowouts, their causes and probability of occurrence are dealt with elsewhere in this evaluation. Here, it is intended to briefly review the fate of oil in the marine environment with particular emphasis on Arctic regions.

7.2 THE FATE OF OIL IN WATER

The movement of oils through and upon waters is a complex phenomenon affected by factors such as spreading, solubility, evaporation, microbial modification, emulsification and condition of the water. The latter may be influenced by physical factors (temperature, wave state) or others, such as particulate content. Thus physical, biological and chemical alterations of oil in waters are all part of a series of events which influence the ultimate impact of such spillages. Equilibrium solubility values may vary considerably within oil types as the proportions and interactions of constituents may be highly variable. Such hydrocarbon solubilities ultimately will influence other, toxicological considerations.

The complexity of the subject is illustrated by Table 7-1. As shown, component solubilities of oil, each potentially exerting its own toxic effect, may be quite different. Such factors combine to create a myriad of variables influencing toxicity - dispersion, sedimentation, fractionation and other factors determining hydrocarbon availability to organisms. McAuliffe (1977) noted that for aromatic hydrocarbons benzene would reach higher solution values than toluene in nonequilibrium conditions with evaporation prevented, which correlates well with Table 7-1. However, such situations are complicated because of the fact that benzene and toluene concentrations found in waters, which are allowed to equilibrate with crude oils, are almost equal (due to the dominance of low molecular weight components in non-evaporative systems).

McAuliffe (1977) reviewed the fate of oil in waters noting that the character of oil dispersion is determined by numerous factors such as wind, waves, currents, temperature, salinity, nutrients, microbes and oil type. Gravity and surface tension are the basic determinants in the natural tendency of oil to spread across calm waters. Wind and currents only accentuate this tendancy which leads, in turn, to the break-up of the oil into discreet patches. Although the spreading of spilled oil is viewed as a mechanism which increases detrimental effects in marine settings, it also exposes the oil to weathering (including evaporation) and increased potential microbial action through larger surface areas.

Water in oil emulsion formation (the "chocolate mousse") of oils accelerates dispersion of the oils and although oil particles may form, remaining suspended in

Table 7-1.

Representative solubilities of hydrocarbons in distilled water (room temperature). (Adapted from Shaw (1977)).

Hydrocarbon	mg/l
n-pentane	38.5-39.5
n-hexane	9.47-9.5
n-heptane	2.24-2.93
n-octane	0.431-0.66
n-decane	0.052
n-dodecane	0.0037-0.00182
l-hexane	50
1,5-hexadiene	169
l-hexyne	360
cyclohexane	55-66.5
benzene	1740-1790[1]
toluene	515-627
biphenyl	7.45-7.48
naphthalene	31.3-34.4
l-methylnaphthalene	25.8

1 Benzene and toluene usually comprise up to 70-85% of the total dissolved aromatic fractions of crude oils.

the water column, many of the viscous 'globs' may wash up onto beach or estuarine areas or sink.

McAuliffe (1977) noted that with lighter (less viscous) oils surface slicks may rapidly disappear, sometimes overnight. In colder waters, such as Cook Inlet Alaska, Kinney et al. (1969) found that dissipation of crude oil occurred rapidly within 5 days. Thus, specific gravities of oils may profoundly influence surface residence times and, hence, impacts to surface-dwelling animals. The disappearance of surface slicks, however, is usually accompanied by dispersion down into surficial waters. Rapid, unaltered sinking of oils appears generally limited to heavier, viscous oils.

Vapour pressure and solubility determine the rates at which volatile hydrocarbon fractions will either evaporate or move into solution. The competitive processes which occur simultaneously are among the first of a series of changes which spilled oils undergo. The physical and chemical characteristics of the oil will determine the rate at which solution/evaporation will proceed as influenced by wind, temperature and the state of the sea.

Rates of evaporation are directly proportional to wind velocities (assuming constancy in related factors) and the rates of solution are determined by the speed which dissolved hydrocarbons are removed from the oil-water interface. McAuliffe (1977) illustrated that the actual amount of dissolved hydrocarbon in sea water below oil slicks is very low (less than 1 ug/l) because there is no opportunity for the water to equilibrate with the spilled oil. This led him to conclude that bioassay tests which equilibrate fresh oil with water for several days are "very unrealistic" since such equilibration allows naphthalenes (important sources of toxicity) to attain their highest concentrations: "The entire field of bioassay testing with petroleum products needs re-evaluation and research under conditions that simulate more realistically the exposure durations, and the compositions and concentrations of hydrocarbons likely to occur in the environment."

So while it may be necessary to re-examine the basic assumptions of hydrocarbon (dissolved) toxicology it would be fair to assert that a blowout of oil, constituting a sub-surface oil discharge perhaps agitated by the presence of

natural gas, would provide the greatest opportunity to dissolve hydrocarbons from oil into the water column. McAuliffe (1977) noted that in an area of the Santa Barbara Channel which receives 50 to 100 barrels of oil per day from sub-surface seeps, benzene and toluene each reached maximum concentrations in waters near the seepage of only 0.08 ug/l. This is far less than the solubilities shown earlier (Table 7-1) for principal hydrocarbon components. It is possible, however, that in cases of a blowout, where oil volumes discharged may be much higher, the dissolved values may be higher. There is an unfortunate lack of data on this point.

In their review of petroleum in the marine ecosystem Hardy et al.(1977) noted that the largest proportion of oil reaching the oceans does so either as a thin film or as particulates. In being introduced from massive, surface spills from sources such as tankers oil movement is controlled by emulsification processes influenced by oil viscosity, density and temperature. As such, Hardy et al.(1977) divided further dissipation of the oils into two broad groupings of processes:

(i) processes that redistribute the hydrocarbons.

(ii) processes that degrade the hydrocarbons.

Redistributive forces include evaporization and dissolution both of which are significantly influenced by the hydrocarbon type and climatic conditions. Degradative processes through photo-oxidation, bacterial action and absorption/injestion by other marine biota remains largely a topic of intensive investigation primarily in the area of bacterial oxidation. Although organisms in the open sea which are capable of oxidizing oils occur in low concentrations the introduction of oils in the presence of nutrients and oxygen has been observed to promote certain micro- organisms and lead to metabolic attack on the hydrocarbons. Gatellier et al.(1973) and Gibbs(1975) found that microorganisms tend to attack the lower n-alkanes (up to C_{20}) most rapidly including the aromatic fractions. Chemical oxidation is most effective on branched chain alicyclic and higher aromatics while biota tend to remove long-chain n-alkanes (Hardy et al.1977). They also note that although non-hydrocarbon fractions of oils may constitute a relatively large proportion of the oil, research concerning the fate of these substances is incomplete.

A key to understanding the effects of oil spills and their toxicity in the marine environment rests with the composition of the oil and also on the location of the spill. If a spillage occurs on the open sea effects, at least in the water column, may be minimal. In more sheltered areas impinging on coastal zones the impact of the oil can be much more pronounced (Hardy *et al.*, 1977).

In a marine situation in which hydrocarbons are present organisms able to withstand the oils and utilize them as a substrate or metabolically will flourish, whereas populations of organisms which are less adaptive will decline. Hardy *et al.*(1977) found in their review that the response to oils by plankton, eggs and larvae varied widely some species being very susceptible to low concentrations and others being "relatively indifferent". While this was also found to be the case for benthic species a trend of the larger specimens being more able to withstand oils in sediment was detected. At the time of their review there was little substantive evidence to indicate that oils were moved or concentrated along marine food chains however, it was noted that some marine species could assimilate relatively large amounts of polynuclear aromatic hydrocarbons and others could store substantial quantities in their tissues.

Hardy *et al.*(1977) make the point that marine research on the impacts of oils has centered largely on the impacts of large, concentrated inputs to the oceans and that such an emphasis is surprising since most studies indicate that low-level inputs of hydrocarbons are the primary pathway for entry to ocean waters. The authors note that some estimates have postulated that as much as 10^7 tons of hydrocarbons may be present in the oceanic biomass of the globe which, if accepted, represents an amount greatly exceeding estimated world petroleum inputs.

Ahearn (1974) noted that most of the hydrocarbons found in the oceans originate from biological processes (Table 7-2) which include the decay of planktonic organisms. Crude oil inputs were estimated to constitute only a small proportion of the total hydrocarbon content if they occur at estimated input levels of about 6×10^6 metric tons/year. However, of the crude oil found in the oceans, activities of man account for most of it (Table 7-2).

Cormack and Nichols (1977) classified "non-persistent oils" as petroleum products having boiling points from 30-380°C. (This lighter range of oils is typical of that

Table 7-2.

Estimated Sources of Oceanic Hydrocarbons (1970-1973) (A) and estimated sources of crude oil to the oceans (B). (Adapted from Ahearn (1974)).

A. Source	% of Total[1]
Decaying biological material	50
Shipping operations	18
Terrestrial runoff	17
Atmospheric fallout	8
Natural seepage	4
Shipping/production accidents	3

B. Source	Metric Tons ($x10^6$)
Shipping operations	1.15 - 4.0
Offshore oil operations	0.09 - 0.1
Shipping/well accidents	0.3
Natural seeps	0.3 - 0.6
Total crude	1 - 5

1 Estimate based on input levels of $6\text{-}12x10^6$ metric tons/year

which could be expected from a serious underwater blowout). In their experiments they found that in the North Sea crude oil from that basin when experimentally released onto the sea surface rapidly dispersed down into the water column, 42% moving into the top 5m of water within 8 hours. The authors concluded that with light crude oils and volatile hydrocarbon products dispersion and evaporation may result in the complete removal of oil from the surface of the sea. More persistent oils could require the use of dispersants which increase the rate of dispersion into the water. By using dispersants and modified mixing apparatus in their experiments the authors found that under tidal conditions light crude oils rapidly diffused through the water.

7.3 THE SPREADING OF SPILLED OIL IN LANCASTER SOUND-BAFFIN BAY

Predictions of the movement of oil spilled onto, or below, the surface of Lancaster Sound are complicated by sub-sea currents, which are known to be complex in this region, and considerations of wind and ice movements.

Ice usually forms in Lancaster Sound by early October and remains as a 10/10 ths coverage usually until mid-June for east-central regions, at least. The ice in the Sound generally tends to move eastward although barriers of landfast ice are generally present around the Sound until July when breakup opens the bays and inlets. The current regime of the Sound and of Baffin Bay are presently a subject of intensive study by Petro-Canada. These studies, in conjunction with atmospheric investigations, will be combined into a comprehensive oil spill trajectory estimate for the region.

Milne and Smiley (1978) indicated that in eastern Lancaster Sound surface currents would probably strongly influence oil movements on the water surface during the open-water season and, therefore, prime locations for contact with the oil would be Bylot Island, Navy Board Inlet and the Borden Peninsula.

The effect of winds could significantly distort the movement of the oil with prime impacts probable around the northern half of Bylot Island (extending down into Navy Board Inlet) and down the eastern coastline of Bylot and Baffin Islands. Possible movements could include penetration of the oil further west and could include impingement upon Devon Island.

In such hypothetical analyses it is necessary to proceed from a number of assumptions not the least of which concerns the duration of an oil blowout. Here, a worst-case assumption is that an uncontrolled flow would not be capped by a relief well until the next drilling season. The complexities of a "same-season" relief well capability for the drilling proposal are presently being reviewed by Petro-Canada, however, the analysis is under development and will be presented at a later date.

The worst-case assumption of a continuous oil flow for 12 months permitted Milne and Smiley (1978) to estimate

the amount of oil which might be expected to evaporate, disperse and become stranded on beaches during the open water season.

Almost certainly if an oil blowout did occur the oil would be a light grade which would be susceptible to evaporative loss upon reaching the surface if no ice were present. Therefore, the analysis of Milne and Smiley (1978) which indicated that 19% of the oil surfacing from a blowout would be dispersed each day into upper layers and that up to 50% of the oil would evaporate within the first few days is well-founded. Based on evidence of evaporative losses of Prudhoe Bay crude oil in Cook Inlet, estimates from the Ekofisk blowout and our knowledge of Norman Wells crude oil (40% can evaporate within 24 hours) an assumption about an hypothetical spill in Baffin Bay - Lancaster Sound could validly include evaporative losses of 523 m^3/day based on a surfacing volume of 950 m^3/day (55%).

Losses due to dispersive effects (mixing in the surface layers of water) could further account for from 25% to 45% of the residual oil (oil remaining after evaporative and solution losses) in a period of from 2-6 days. Based on these assumptions, disposition of oil during August and September could be shown as principally impacting Bylot Island's northern coastline and moving south-easterly into Baffin Bay (14% and 8% of the total oil blowout volume, respectively).

All such hypothetical scenarios depend, in large part, on surface current regimes and wind velocities both of which are presently known only tenuously. Research in this area is continuing and the analysis of Milne and Smiley (1978) will be evaluated further as such data are obtained. Near-shore surface currents are planned to be more fully investigated in 1979, as these processes will strongly influence the rate and extent of oil impingement along the coast of Bylot Island.

During the months of October and November any spilled oil would be progressively restricted, by the growing ice, toward the open water areas of Baffin Bay. Oil caught in landfast or sea ice would be incorporated into it and remain so confined until released at the next spring melt. As the winter months advanced, heavy ice layers would trap oil originating at depth and entrain it in movements out of Lancaster Sound and into Baffin Bay. The ice would incorporate progressively larger quantities of the oil into lower

layers effectively preventing any evaporation, dissolution or microbial activity. Milne and Smiley (1978) estimated that such entrained oil would move with the ice at a net rate of 13 to 20 km/day in a swath about 4 km wide. This oil will then emerge up through the ice in the spring along the line of the trajectory into Baffin Bay. By May the remaining, residual oil would run off with melt waters from the ice.

With the breakup and subsequent clearing of ice from Lancaster Sound in the spring the oil would accumulate up against the ice-water interface at the edges of fast ice. At this time of year the landfast ice around shores would effectively seal off some coastal areas from the oil and prevent it from entering into some inlets. Thereafter, the oil movements would largely be similar to that described previously for August. In summary, the hypothetical oil blowout described in detail by Milne and Smiley (1978) would, in the course of a year, be expected to deposit approximately 6% of the total spilled volume (21,000 m^3 or 132,000 bbls) along the southeast perimeter of Lancaster Sound, chiefly on Bylot Island.

Planning for countermeasures against such spillages (including discussions of relief-well capabilities and spill trajectories) will be presented at a later date in subsequent submissions by Petro-Canada.

7.4 MICROBIAL AND PHYSICAL-CHEMICAL DEGRADATION OF CRUDE OIL

The degradation of oil by micro-organisms has been cited as probably being the major way hydrocarbons are removed from the environment (McAuliffe, 1977). This biodegradation has been documented for extremely cold environments (Kinney *et al*.1969, Robertson *et al*.1973, Cundell and Traxler, 1973, Atlas 1973, 1974, Button, 1974, Traxler and Cundell, 1975, 1976). McAuliffe (1977) summarized some of their findings which showed a loss of hydrocarbons ranging from 21 to 97% within 3 to 70 days (Table 7-3).

It is known that the rate at which microbes modify oil is dependent on oil type, the availability of nutrients and oxygen, and the temperature of water. In waters which are oxygen-deficient, the rate of degradation may be very slow. In this regard, photochemical modification of the oil slick may become important. In Arctic regions sunlight in summer months may be intense and of long duration, while in winter the reverse is the case. Oxidized hydrocarbon components are usually more water-soluble and such characteristics may promote disperal and biodegradation. Photo-oxidation of oil occurs more slowly than processes such as evaporation of the volatile components. McAuliffe (1977) cited evidence which suggested that aromatic hydrocarbon fractions, which are known to be photosensitive, have been thought to be altered in samples taken of dispersed oils collected in surface waters along tanker routes.

There is no doubt that micro-organisms which are able to degrade petroleum products occur in the Arctic oceans. However, Atlas (1977) noted that such organisms constitute only a small percentage of the indigenous heterotrophic microbial populations (from 1%-10%). He found that the natural rates of degradation from abiotic and biotic processes were slow with maximal losses from experimental spillages being less than 50% during the Arctic Summer.

In summer, counts of hydrocarbon - degrading bacteria in sediment offshore Point Barrow, Alaska were found as being considerably higher than in winter. In surface ice, the concentrations of hydrocarbon - degrading organisms were an order of magnitude lower than in the water just underneath the ice (Atlas, 1977). That these heterotrophic communities respond to hydrocarbon additions was shown by the research through experimental additions to waters. Indeed, in laboratory flow-through experiments Horowitz and Atlas (1976) found

Table 7-3.

Biodegradation rates of crude oils at various temperatures (Adapted from McAuliffe (1977)).

Crude Oil Type	Prudhoe Bay Lab		Prudhoe Bay Field		Cook Inlet Lab	Prudhoe Bay Lab		Cook Inlet Lab	S.Louisana Field
Conditions									
Temp°C	5	25	5-12		10	-1.1	8	10	30
Nutrients Added	NO	NO	NO	YES	NO	YES	YES	NO	NO
Percent lost after	21	39	60	80	Complete	61	82	90	97
Given Days	3	3	35	35	30-60	70	70	30	21

that after several weeks exposure Arctic microbial populations using hydrocarbons rose to 100% of the microbial community.

In summer experiments *in situ* at Prudhoe Bay, Alaska (Atlas, 1977) found that evaporation accounted for 30% of oil losses although such losses are generally restricted to low molecular weight compounds. The exposure of the oil to indigenous microorganisms doubled those amounts (30% lost to evaporation and 30% lost to biodegradation)(Table 7-4). The degradation was increased by additions of nitrogen and phosphorus nutrients. Their work further indicated that all the component classes of the Prudhoe Bay crude oil were being degraded at relatively similar rates. They speculated that cometabolism of petroleum at low rates of biodegradation in cold Arctic marine waters accounts for this surprisingly uniform rate of breakdown of the various components of the oil.

Even with the physical and biotic processes which degrade hydrocarbons residual oils are still found even after months of exposure or "weathering". While Arctic waters possess the potential for degrading oils the amounts and rates of such processes vary seasonally (less in winter) and are slow. Atlas (1977) considered that less than 50% of the hydrocarbons in an Arctic marine oil spill could be expected to be lost during an entire summer from natural biotic and abiotic processes. During winter the expected rates of biodegradation (and physical losses) would be very low.

Arhelger *et al.*(1977) demonstrated alkane metabolism is a not uncommon capability of the near-surface marine microflora a capability that probably extends to all soluble crude oil components. They further noted that low temperature and nutrient availability may often be restrictive to biodegradation of oils only in the oil phase containing oil-water mixtures. It is possible that enhanced biodegradation of hydrocarbon emulsions in sea water may be facilitated by nutrient and bacterial additions.

Colwell *et al.*(1978) investigated the fate of oil washed ashore from the Straits of Magellan after the wreck of the V.L.C.C. Metula. Samples taken from the sandy Chilean beach contaminated with the oil indicated the presence of a cold-tolerant, petroleum-degrading population of microorganisms. The oil had induced significant shifts in the structure of the microbial populations. These populations slowly degraded the oil, however temperature, they concluded,

Table 7-4.

Degradative losses of Prudhoe Bay crude oil exposed to heterotrophs (Adapted from Atlas (1977)).

Sample	Exposure	Time (days)	Wt.Loss (mg)	% Loss
Poisoned Control	Summer-water *In situ* Prudhoe Bay	42	300	30%
Summer[1] water	Prudhoe Bay *In situ*	42	600	60%
Summer water	Barrow-Flow through	51	20,000	15%
Winter	Surface Ice	28	120	12%
Winter	Underside Ice	21	90	9%

1 The author noted that these results may be misleading since the summer was very cold the average temperature being 2°C.

did not appear to be a limiting factor for the degradation in the antarctic marine environment. They found that weathering of oil deposited on beaches in such cold climates could exert a significant effect at removing residues, in concert with microbial degradation, however, if the tar was buried or formed thick layers of tar the effectiveness of natural mechanisms of removing the hydrocarbon was impared. As such, the residual tars were expected to remain on the beaches until physical processes redistributed or eroded the oil. All three processes (microbial degradation, weathering and mechanical (wave actions) contributed to the erosion of the oil from the beaches, however, a complete removal of the oil was thought to require perhaps decades.

Atlas et al.(1978) noted that contamination of arctic marine ecosystems with petroleum hydrocarbons generally results in "increased numbers of heterotrophic and oil-utilizing microorganisms and an increased percentage of oil-utilizing microorganisms in the heterotrophic microbial community. The petroleum hydrocarbons appear to remove a limitation of available organic carbon for the growth of microorganisms in these ecosystems." Importantly for arctic, icy waters they concluded that the microbial response to oil is most limited in situations "in, on or under-ice ecosystems where there may be other nutrient or temperature limitations for microbial activity." (Table 7-5). Their comparative experimental approach indicated that less degradative change occurs to oil during winter when over ice than during summer when on water. They opined that the ice cover limited the evaporative losses from the oil and found that the rates of degradation of the oil in arctic ecosystems was very slow after initial abiotic weathering. Oil spilled on water during summer underwent a 22% loss in one month which they ascribed to be largely a result of evaporation of the lighter fractions of the oil. No biodegradation of oil over ice occurred during the winter. Also, when spilled under ice the compositional changes were slow, few having been detected over a three weeks period.

Loutfi (1973) cited an interesting study which indicated that the complete oxidation of one litre of crude oil requires "all the dissolved oxidation in 400,000 litres of air-saturated seawater at 15^{o}C. This figure is somewhat misleading due to the tendency of oil to spread over wide areas and, therefore, be made available to relatively large volumes of water. However, it does give an indication of the problems which attend marine microbial degradation at very

Table 7-5.

Microbial populations before and 30 days after oil contamination (From Atlas et al.(1978)).

Ecosystem	Oil Utilizing Microbes (no./ml or no./g)			
	No Oil		Oiled	
	Estimated Number	Estimated % Heterotrophs	Estimated Number	Estimated % Heterotrophs
Over Ice	1×10^{-1}	0.01	3×10^{-1}	0.03
Open Water	5×10^{1}	0.5	7×10^{-3}	50.0
Under Ice	1×10^{0}	0.1	5×10^{0}	0.5
Sediment	3×10^{3}	0.1	-	-

low temperatures below ice. From the point of view of potential oxygen availability and temperature under ice situations could only be described as minimal".

7.5 A DETAILED COMPARATIVE STUDY OF THE NORTH SEA AND BAFFIN BAY

Johnston (1977) attempted to project the impact of the North Sea oil development on fishery resources of that region. He recognized two primary impacts of hydrocarbons as short-term (toxicity) and long-term (residual) effects listing the theoretical impacts to fish production in the former category as:

- -toxicity of whole fresh crude
- -inhibition of primary production by pentane fractions
- -inhibition of primary production by octane fractions
- -toxicity of soluble oil components to fish

Data were cited which described crude oil toxicity as falling within ranges for various marine organisms:

-marine fish	10^4-10^5mg dm^{-3}(ppm)
-crustaceous plankton	10^3-10^5mg dm^{-3}(ppm)
-larvae	10^2-10^3mg dm^{-3}(ppm)

The most susceptible segment of marine life was deemed, for the purpose of his study, as sensitive crustaceous plankton. He concluded that the losses of fish stocks resulting from the toxic effects of fresh crude oil to crustaceous plankton (in the short term) was negligible since even "major oil spills do not sustain short-term toxic conditions to more than a fraction of 1 m" (Table 7-6).

In examining pentane fractions which are known to inhibit phytoplankton, photosynthesis and multiplication but which are known to also be quite volatile (and therefore of short duration). Johnson (1977) found that with a limiting time of 4 days ascribed to larger spills the equivalent losses of fish production was significant for larger spills but at a low-level of loss per unit area (Table 7-7). The maximum loss was calculated at 26.2 t year^{-1} or 0.0033tkm-2year-1. Losses of primary productivity due to the octane fraction of oils are more considerable as these fractions are less volatile and more inhibitory than other, lighter fractions. If one regards the equivalent fish loss due to the inhibition of primary production by octane fractions associated with an oil slick mean annual losses were estimated at about 196 t year-1 (Table 7-8). The

Table 7-6.

Equivalent fish loss due to the toxicity of fresh crude oil to sensitive crustaceous plankton in the short term (adapted from Johnston, 1977).

M	A	Z	L	I	IxLxA
2.5	3.2×10^{5}	0.008	3.5×10^{-5}	100	0.0011
50	2.9×10^{6}	0.017	7.4×10^{-5}	10	0.0021
1,000	3.8×10^{6}	0.026	1.13×10^{-4}	1	0.0043
10,000	10^{7}	0.100	4.38×10^{-4}	0.2	0.0088
100,000	4.4×10^{7}	0.227	9.9×10^{-4}	0.04	0.0175
400,000	1.2×10^{8}	0.333	1.46×10^{-3}	0.02	0.0350
					0.0688*

* Total loss as fish is 0.0688t if all spill categories considered are envisaged as 0.0109t km^{-2} per year

M magnitute spill in tons

A area of oil slick at 24 h

Z depth of layer (m) yielding concentration of 10^{3} gm^{-3}

L loss fish (t) using $7 gm^{-2}$ standing crop zooplankton equivalent to 0.875 g m^{-2} fish assuming 50% mortality and uniform vertical distribution of zooplankton to 100 m depth

I incidence of oil spills per year

IxLxA loss fish per year (t $year^{-1}$).

Table 7-7.

Equivalent loss of fish due to inhibition of primary production by pentane-like substances (Adapted from Johnston, 1977).

M	A_{tox}	T	I	ATLI
2.5	$4x10^4$	1.4	100	$7.3x10^{-3}$
50	$8x10^5$	10	10	$1.1x10^{-1}$
1,000	$1.6x10^7$	70	1	1.7
10,000	$1.6x10^8$	96	0.2	0.4
100,000	$1.6x10^9$	96	0.04	8
400,000	$6.4x10^9$	96	0.02	16
				26.2t
				(0.0033t km^{-2} $year^{-1}$)

M magnitude of spill in tons

A_{tox} assuming 10m layer area of patch attaining 1 gm^{-3} pentane and total parimary production present

I incidence of oil spill per year

L primary production 100 g (m^{-2} $year^{-1}$ = 0.001305 t fish km $^{-2}$ hr^{-1} (assuming 50% inhibition,m 1gC = 16g wet wt. phytoplankton) (70t wet phytoplankton production = 1 t wet fish production) Pentane fraction = 16t/100t crude oil

T assumed/calculated duration of effect in hours.

Table 7-8.

Equivalent fish loss due to inhibition of primary production by octane fractions associated with an oil slick (Adapted from Johnston, 1977).

M	V_{tox}	A_{20}	A_{ult}	D_{24}	V_{24}	T_D	A_{20}/A_{ult}	L	LxIxT
2.5	$2x10^7$	10^6	$3.2x10^5$	$6.5x10^2$	$2.6x10^8$	0.077	3.1	0.031	3.1
50	$4x10^8$	$2x10^7$	$2.9x10^6$	$1.9x10^3$	$7.6x10^8$	0.526	6.9	0.062	6.2
1,000	$8x10^9$	$4x10^8$	$2.8x10^7$	$2.2x10^3$	$8.8x10^8$	9.09	14.5	12.5	12.5
10,000	$8x10^{10}$	$4x10^9$	$1.6x10^8$	$3.5x10^4$	$1.4x10^9$	57.1	25.0	124.57	24.9
100,000	$8x10^{11}$	$4x10^{10}$	$8.6x10^8$	$7.5x10^3$	$3.0x10^9$	267	46.5	1,250	50
400,000	$3.2x10^{12}$	$1.6x10^{11}$	$2.4x10^9$	$1.25x10^4$	$5.0x10^9$	640	66.7	4,992	100

mean annual loss fish = 195.7 t

M magnitude of oil spilled

V_{tox} volume (m^3) with 0.02 gm^{-3} for octane fractions at 16t/100t crude oil

A_{20} area (m^2) with 20m depth octane solution

A_{ult} maximum calculated slick area

D_{24} diameter (m) of oil slick at 24 hours

V_{24} volume (m^3) below slick to 20 m at 24 hours

T_{Drift} days at drift rate of 20 km day^{-1} to give V_{tox}

L loss as fish assuming D_{24} x 20 km, T_{DRIFT} and 0.03132 to equivalent fish day^{-1} km^{-2}

equivalent loss of fish due to attachment of weathered oil to plankton was estimated at an annual loss of 259 t.

In assessing the toxicity of soluble oil components to fish eggs and larvae considerable difficulty is encountered as extreme extrapolation from laboratory toxicological investigations is required and there is always the possibility of longer-term effects on organisms which survive the initial exposure. However, Johnston (1977) considered that extrapolation from the laboratory tests to the open sea situation was not an underestimate of the impact of the oil since the open sea often offers more severe mixing, extraction and exposures to standing stocks. Annual losses were estimated through the calculated values as at 97 t (Table 7-9).

The author went on to assess additional impacts affecting fisheries production such as long-term residual effects, behavioural responses, tainting and natural gas impacts. The summary conclusion of these calculated values were computed for a mean annual loss and the loss attaching to a 400,000 t oil spill disaster. The total losses on average were calculated as being 500-600 t fish per annum but up to 13,000 t fish for a disasterous (400,000 t) spill. When compared with the amount of fish harvested annual from the North Sea area by Europeans (4.36 million tons)even the worst-case (disasterous) spill losses are insignificant (0.3%), much less than factors such as over-exploitation.

An interesting confirmation of most of Johnston's (1977) hypotheses of oil impact on marine biota of the North Sea is provided by Mackie et al.(1977). During the Ekofisk "Bravo" blowout a mixture of oil and gas was ejected from the production platform up to 50 m above sea level for 7.5 days. The authors estimated that between 20-30,000 tons of oil were released forming a slick estimated to be 4,000 km^2.

It was estimated that only 10% of the released oil could be accounted for in the water column suggesting that dispersion occurred in much larger volumes of water than was accounted for or that considerable quantities of oil were lost to sediments or to the atmosphere. Neuston tows recovered considerable numbers of tar balls ranging in size from "pinhead size" up to 4 g. The authors concluded that although a very large volume of oil was spilled into the ocean by the blowout, high concentrations of the oil were not found in the water immediately after the flow was stopped. After 2 months, positive identifications of oil in the water

Table 7-9.

Loss of fish eggs and larvae due to toxicity of the soluble fraction (adapted from Johnston, 1977).

M	M_{tox}	Ix1/3	A_{tox}	T	AxTxI	Depth	AxTxIxZ
2.5	0.125	33.3	$3.2x10^{2}$	0.83	$0.045x10^{-8}$	2/3	$0.030x10^{-8}$
50	2.5	3.33	$6.25x10^{3}$	5.54	$0.596x.0^{-8}$	2/3	$0.4x10^{-8}$
1,000	50	0.3	$1.25x10^{5}$	13.34	$2.87x10^{-8}$	2/3	$1.91x10^{-8}$
10,000	500	0.067	$1.25x10^{6}$	32.6	$14x10^{-8}$	2/3	$93x10^{-8}$
100,000	5,000	0.013	$1.25x10^{7}$	45.0	$38.7x10^{-8}$	2/3	$25.8x10^{-8}$
400,000	20,000	0.007	$5x10^{7}$	51.7	$89.1x10^{-8}$	2/3	$59.7x10^{-8}$

M magnitude of oil spill (t)

m_{tox} wt. of soluble fraction (t)

Ix1/3 incidence x 1/3

A_{tox} Area (M^2) of 20m of m_{tox} yielding 20 gm^{-3}

T duration of patch; area egg production = $8x10^{10}m^2$

2 layer depth eggs/larvae = 30 m

2/3x depth layer - polluted water layer only 20m of 30m egg layer (2/3)

column were rare. It was concluded that because of the high volatility of the oil evaporation was probably the most important of the rapid, redistributive processes which dispersed the oil, although some oil appeared to have reached bottom sediments.

It is difficult to draw valid parallels between the study by Johnston (1977) in the North Sea and hypothetical oil spills in Lancaster Sound or in Baffin Bay. The pronounced lack of reliable fisheries data on standing stocks of the Eastern Arctic marine environment prevents any approximation of estimated populations of fishes. Also, the impact of oils which are trapped beneath ice for several months may be severe as the ice would prevent the escape, by evaporation or dissolution, of hydrocarbon fractions as occurred in the North Sea. Johnston's (1977) study is, however, instructive of the relative estimated impact of a massive, offshore petroleum development inside a region having an established commercial fishery.

The petroleum development in the North Sea is several orders of magnitude greater than that which could be projected for "worst case" analyses of four exploratory wells in Baffin Bay. Unfortunately, we have absolutely no information about the type, quality or even existence of crude oil in Baffin Bay sediments. As such, comparisons or extrapolations with known oils is difficult and hypothetical. However, if a blow-out were to occur it is most probable that the type of oil would be a light fraction as heavier, more viscous oils are not likely to be released in cold waters. Johnston (1977) used a light crude oil fraction in his analysis, so some comparisons are possible here. Using Johnston's "worst-case" 400,000 metric ton spillage of oil, the reduction of harvested fish was insignificant (0.3%). It is exceedingly unlikely that an exploratory oil well would release 400,000 t of oil to Baffin Bay. However, if we assumed as an extreme "worst-case" that entrapment of that volume of oil below ice increased the exposure of the oil to relatively smaller populations of fish, as compared with the North Sea, one could generously assume that the impact of such a massive release of oil might increase the impact on populations by an order of magnitude, from Johnston's analysis, of from 0.3% to 3%. It is possible that if populations of fish are smaller in Baffin Bay than in the North Sea the fact that the former represents a much larger area of ocean than the latter may partially offset such discrepancies in the comparison of relative impacts.

The point in all this is not to attempt to diminish the probable important consequences of a massive oil spill to fish populations of Baffin Bay. Instead, an attempt is made to quantify the hypothetical impact of such a spillage. What is needed, of course, is much more data on the size and distribution of the fisheries of that region. Until such time as such data are available quantitative attempts at impact scenarios will not be feasible. Such data are not usually forthcoming until commercial fishing fleets actively begin operations in a region. Here, it is intended to at least identify the factors necessary for quantification in attempting relative, empirical analyses.

7.6 MECHANICAL DISPERSAL OF OIL ON SHORELINES

While the type and the volume of oil deposited on marine littoral areas will affect the dispersion of the oil, it has been found that the single most important determinant in mechanical dispersal is from mechanical energy (winds, waves, tides, water levels and ice) (Owens, 1978). Other energy inputs include biological, chemical and thermal sources, however, the persistence of stranded oil decreases as mechanical energies increase. It has been found that oil on intertidal zones with a high wave-energy environment may be rapidly eroded and dispersed by the wave action. This process of dispersion may act within only a few weeks (Owens, 1978). In low energy environments such dispersal (lagoons and sheltered bays) may extend for decades (Vandermeulen and Gordon, 1978).

The hydraulic action of coastal waves exerts its dispersing effect through abrasion and redistribution of sediments and deposited oil, alike. If, however, oils form a thick deposit the rate or erosion may be slowed even in areas of high energies. The potential complexity of this process of dispersion was elaborated by Owens (1978) in noting that mechanical dispersion is not solely due to wave force but that sediment moved by wave action could further abrade the stranded oil.

Further, timing of oil deposition on beaches will also determine the persistence of the oil as beaches are subject to considerable changes in rates and levels of wave action (seasonal, tidal and weather). As an example Owens (1978) concluded that in cold, polar climates the mechanical dispersal of oil can be much reduced over that in more temperate areas because annual average energy levels at shorelines are reduced by the presence of anchor ice. The depth of penetration of the oil into the sediments and the effects from the creation of an asphalt layer resulting from the deposition of large volumes of oil will also influence erosonal characteristics.

Of particular interest for arctic areas is the interaction of beach ice with potentially deposited oils. Owens (1978) noted that such ice formations could seriously impede oil erosion by waves by preventing contact with beach areas. In the arctic, the potential erosonal characteristics of beach areas is determined not so much by the generation of waves or by the fetch area for them, but rather by the time available (ice-free) for shoreline abrasion (Fig. 7-1: Owens

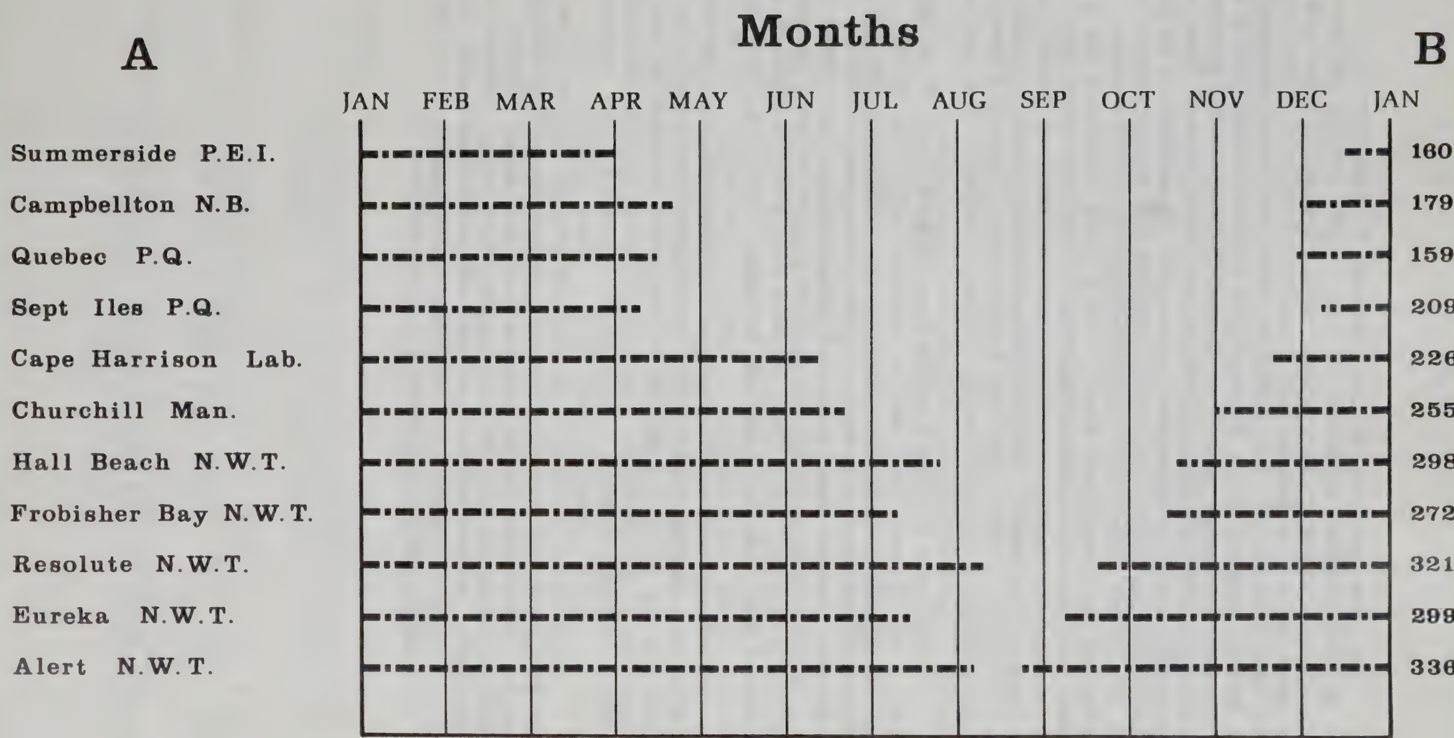


Fig. 7-1 (A) Duration of ice on nearshore zones during average years.
(B) Number of days per year with frost.

(1978)). As wave generation is limited in the Arctic, because of the damping effects of ice, high levels of wave activity are relatively infrequent and, therefore, so are the periods available for potential erosion of oils. This, coupled with the effects of ice pushing both sediment and oil up off the beach (potentially depositing hydrocarbons above wave action limits) combine to lower the potential rates of erosion. Owens (1978) further notes that freezing and thawing of beach sediments in the Arctic may act to entrap oils deposited into the sediment in summer as the oils may penetrate down to the frost table and subsequently be frozen over. For these reasons he concluded that "heavy oils stranded in a low-energy environment, particularly in cold or arctic regions, would be expected to persist for tens of years with little loss of volume". On the other hand, it is possible that shore-fast ice may protect beach areas from oil washing ashore for limited times during spring or fall.

Clark and Finley (1977) noted that in 1970 a spill of 14,000 l of diesel fuel and a heavier fuel oil which occurred at Resolute Bay resulted in the oiling of up to 1.8 km of non-uniform beach gravel. Some areas were heavily contaminated and the average depth of penetration was about 7.6 cm. Ice cover confined the spilled oil at the head of the harbour for somewhat less than a week but wind changes eventually moved the oil and ice out to sea.

In instances such as this and others, for instance the site of the large (1.67×10^6 l) diesel fuel spill at Deception Bay in 1970, it would be valuable to return to the spill locations and observe the persistence of the residual oils after 9 years.

Depending on the type and amount of oil spilled residual sediment concentrations may range up to 12,000 mg/kg (dry weight) (Hyland, 1977) in areas of low wave energy. Spillages of oils in significant quantities will create coastal management problems particularly as such spillages often increase in direct proportion to the development or transportation of hydrocarbon resources in a region.

REFERENCES

Arhelger, S.D., Robertson, B.R. and Button, D.K. (1977). Arctic hydrocarbon biodegradation. In: Fate and effects of petroleum hydrocarbons in marine organisms and ecosystems. D.A. Wolfe (Ed.). Pergamon Press, 478 p.

Atlas, R.M. (1973). Fate and effects of oil pollutants in extremely cold marine environments. U.S. Defense Documentation Center, AD 769895.

Atlas, R.M. (1974). Fate and effects of oil pollutants in extremely cold marine environments. Office of Naval Res., AD/A-003 554.

Atlas, R.M. 1977. Studies on petroleum biodegradation in the arctic. In: Fate and effects of petroleum hydrocarbons in marine organisms and ecosystems. D.A. Wolfe (Ed.), Pergamon Press, 478 p.

Atlas, R.M., Horowitz, A. and M. Busdosh. 1978. Prudhoe crude oil in Arctic marine ice, water and sediment ecosystems: Degradation and interactions with microbial and benthic communities. J. Fish. Res. Board Can. 35: 585-590.

Button, D.K. (1974). Arctic oil biodegradation. Nat. Tech. Info. Serv., U.S. Dept. Comm., AD-AO 14 096.

Clark, R.C. and Finley, J.S. 1977. Effects of oil spills in Arctic and subarctic environments. In: Effects of Petroleum on Arctic and Subarctic Marine Environments and Organisms. Vol. II. Biological Effects. D.C. Malins (Ed.) Academic Press, New York, p. 411-476.

Colwell, R.R., Mills, A., Walker, J.D., Garcia-Tello, P. and Campos-P., V. 1978. Microbial ecology studies of the Metula spill in the Straits of Magellan. J. Fish. Res. Board Can. 35: 573-580.

Cormack, D. and Nichols, J.A. 1977. The natural and chemical dispersion of oil in the sea. Rapp. P.-v. Reun. Cons. int. Expor. Mer, 171: 97-100.

Cundell, A.M. and Traxler, R.W. (1973). Microbial degradation of petroleum at low temperature. Mar. Pollut. Bull., 4, 125-127.

Gatellier, C.R., Oudin, J.L., Fusey, P., Lacaze, J.C. and Priou, M.L. 1973. Experimental ecosystems to measure fate of oil spills dispersed by surface active products. Proc. Joint Conf. on Prevention and Control of Oil Spills. A.P.I., Wash. D.C., 497-504.

Gibbs, C.F. 1975. Quantitative studies on marine biodegradation of oil. I. Nutrient limitation at 14°C. Proc. R. Soc., Lond. B, 188: 61-94.

Hardy, R., Mackie, P.R. and Whittle, K.J. 1977. Hydrocarbons and petroleum in marine ecosystem - A review. Rapp. P.V. Reun. Const. int. Explor. Mer, 171: 17-26.

Horowitz, A. and Atlas, R.M. 1976. Continuous open flow-through system as a model for oil degradation in the Arctic Ocean. Appl. Environ. Microbio., in press.

Hyland, J.L., 1977. A review of oil polluting incidents in and around New England. U.S. Dept. Comm., Nat. Tech. Info. Serv. Rept., PB-271-698, Springfield, Va., 34 p.

Johnston, R. 1977. What North Sea oil might cost fisheries. Rapp. P.-v. Reun. Cons. int. Explor. Mer, 171-212-223.

Kinney, P.J., Button D. and D. Schell. 1969. Kinetics of dissipation and biodegradation of crude oil in Alaska's Cook Inlet. Proc. Joint Conf. on Prevention and Control of oil spills. Amer. Petrol. Inst., Washington, D.C., 333-340.

Loutfi, M.A. 1973. Canadian maritime oil exploration, exploration and transport: A multidisciplinary study. McGill University. 364 p.

Mackie, P.R. Hardy, R. and Whittle, K.J. 1977. Prel. assessment of presence of oil in the ecosystem at Ekofisk after the blowout, Apr. 22-30, 1977. J. Fish. Res. Board Can. 35: 544-551.

McAuliffe, C.D. 1977. Dispersal and alteration of oil discharged on a water surface. In: Fate and effects of petroleum hydrocarbons in marine organisms and ecosystems. Pergamon Press, Toronto. 478 p.

Owens, E.H. 1978. Mechanical dispersal of oil stranded in the littoral zone. J. Fish. Res. Board Can. 35: 563-572.

Robertson, B., Arhelger, S., Kinney, P.J., and Button D. (1973). Hydrocarbon degradation in Alaskan waters. In: Ahearn, D., and Meyers, P. (Eds.). The microbial degradation of oil pollutants, Louisiana State Univ., 171-184.

Shaw, D.G. 1977. Hydrocarbons in the water column. In: Fate and effects of petroleum hydrocarbons in marine organisms and ecosystems. Pergamon Press, Toronto. 478 p.

Traxler, R.W. and Cundell, A.M. (1975). Petroleum degradation in low temperature marine and estuarine environments. Off. of Naval Res., Ann. Rept., No.2.

Traxler, R.W. and Cundell, A.M. (1976). Petroleum degradation in low temperature marine and estuarine environments. Off. of Naval Res., Ann. Rept., No.3.

Vandermeulen, J.H. and Gordon, D.C. 1976. Reentry of 5-year old Bunker C fuel oil from a low-energy beach into the water, sediments and biota of Chedabucto Bay, N.S. J. Fish. Res. Board Can. 33: 2002-2010.

8.0 OILSPILL COUNTERMEASURES

8.1 INTRODUCTION

As noted previously, oilspill countermeasures planning is a subject of intensive study by Petro-Canada. In co-operation with the E.P.O.A., strategies for clean-up and contingency plans are being evolved which will provide a strong base for field operational support. These, and other, detailed plans will be fully elaborated in subsequent submissions to regulatory agencies.

8.2 OIL CLEAN-UP OPERATIONS

The physical containment and recovery of spilled oils in marine areas is a developing technology which is highly influenced by sea state and the availability of materials. The effectiveness of clean-up operations is highly variable as a result of the constraints noted above. Van Cleave (1973) estimated that such operations are typically 20% efficient. While recovery efficiencies may obviously vary, depending on the time and place of the oil spillages, it is certain that even the best technology will not eliminate all spills or allow us to recover the oils so disposed. As a result of this, a rigorous management strategy for hydrocarbon production or transportation developments must include recourse to implementation of effective spill prevention measures and significant clean-up techniques.

It is the intent of Petro-Canada to include such planning strategies in future submissions. The overall intent is to have in place an integrated program of pollution abatement so as to provide a maximum degree of flexibility in responses to incidents requiring clean-up techniques.

8.3 THE CASE FOR OIL-SPILL COUNTER MEASURES USING DISPERSANTS

If an oil spill occurred in Lancaster Sound or Baffin Bay, the use of physical (mechanical) containment methods would be exceedingly limited by the presence of ice and logistical constraints. Burning of the oil on icy or water surfaces may be possible only after the removal of drillships or support vessels from the vicinity of the spill, for reasons of safety.

It is considered that the central line of defence in dealing with potential spillages would be based on a program of actively seeking out, and dispersing, such oils.

Such a strategy has advantages in that it could be quickly put into effect and would aid in removing oils from the flight paths of marine avifauna. The latter would be particularly sensitive to oily water surfaces. Plans which would reduce the potential time of oiling of such birds decreases the potential magnitude of contamination to colonies.

8.3.1 The Basis of Dispersant Action

Dispersants are surfactant chemicals which aid in the formation of oil-water emulsions. Such emulsions may be stable for considerable periods of time. The emulsifier is chemically characterized as having a molecular structure soluble in oil and in water (through polar groups). Droplets formed in oil-water emulsions may extend over a wide size range, the amount of surfactant available determining the size (McAuliffe, 1977). Such emulsions tend to have viscosities which are close to that known for water, which occurs regardless of the viscosity of the oils constituting the emulsion. The reverse is true for water-in-oil emulsions which have viscosities as high, or higher, than crude oils.

"Dispersants" may be variously referred to as detergents or solvent-emulsifiers. The emulsifiers which may be used to combat oil spilled into water are generally made up of a surfactant, an organic solvent which allows the surface active agent to penetrate the oil and mix with it, and a stabilizing agent which will assist in maintaining the emulsion.

The mode of action of dispersants rests on the fact that part of the surfactant molecule (the polar component) is responsible for solubility in water while the apolar component forms a strong association with organic molecules. The dispersant misces with the oil and the water and, if agitated together, begins to form a milky white compound as an oil-in-water emulsion is formed. If stability of the emulsion is maintained, a progressive dilution of the oil in the water is facilitated. The commensurate decrease in the surface tension of the oil tends to allow for the formation of small oil droplets which may be dispersed laterally or vertically throughout the water column.

In cases where an excess of surfactant is present micelles, structures of high molecular weights, may form which may impart the appearance of a colloid. As such, dispersants may act as wetting agents or as solubilizers which may allow hydrophobic compounds to become soluble in water (Loutfi, 1973).

Huang and Elliot (1977) found that emulsified crude oils tended to be stabilized by naturally-occurring suspended solids and, therefore, such stabilized oil might remain in the water column for longer periods of time than in the absence of such particulate material. Of particular interest to Arctic waters was their observation that an increasing salinity of the aqueous phase tended to destabilize such emulsions. They recommended that in order to minimize the hazards to aquatic species "oil drilling and other operations which potentially generate crude oil/water emulsions may be preferentially located in high salinity waters" as the destabilized emulsions would presumably, be removed more quickly from the water column.

Loutfi (1973) listed key points regarding dispersant action. First, emulsifiers disperse oil but they do not degrade it and second, many dispersants may exert a toxic effect on organisms which contact those chemicals. The solvent fractions of the dispersant mixtures is generally considered to be the most toxic component, however, recent progress has been made in identifying mixtures of lower toxicity (Loutfi, 1973).

In sum, a full range of reactions by biota to oil-dispersant emulsions may occur ranging from an increase (Perkins, 1968) through to a decrease in toxicity (Nelson-Smith, 1970). In each case, the toxic reaction is a function of the chemicals used to form the emulsion (including the type of oil) and the species involved in contacting the mixture. Here, a fundamental consideration about dispersant toxicity rests with the degradability of the chemical in the marine environment. As a result, efforts have been directed at identifying the molecular structures of such chemicals which are susceptible to attack by bacterial populations.

One must, therefore, consider that dispersants accelerate the movement of hydrocarbons into the marine environment and as a result place the oil in a much wider contact with the biota of the region. The negative aspect of this action is that in so exposing progressively more biota to the pollutant the contamination and its attendant inimical effects may be extended over wider areas than that resulting from localized spills, including toxic effects from the dispersants. On the positive side, such dispersion exposes considerably more surface area of the hydrocarbon to biodegradation and reduces the concentration of the pollutant in the area of the spill, therefore, potentially decreasing the toxic effects (including physical fouling and smothering).

Controversy has surrounded the use of dispersants on oil spills because of the direct toxicity of many of the chemicals used and also because dispersants tend to accelerate the entry of all of the spilled hydrocarbon into the marine environment. Further, chemical compounds may be formed between the dispersants and the oil, which may themselves exert a synergistic toxic effect. Such arguments are only valid, however, in regions where physical containment or removal of oil spilled oil is feasible. In the Arctic, climatic factors and the often-extreme distances from centers of equipment, combine to present oil-spill contingency planners with formidable obstacles. As such, Arctic regions may warrant special consideration regarding the possible use of dispersant chemicals, in the case of oil spills, as alternative methodologies may not allow for effective mitigation of the spills.

8.4 DISPERSION OF OILS

The addition of dispersants to oils on sea surfaces tends to rapidly dilute the oil by mixing it across and through the water column. In so dispersing the oil effects of wind moving the oil are reduced and current effects are increased. McAuliffe (1977) cites a case in the Gulf of Mexico where dispersants were sprayed from a drilling platform to an oil spill. While the amount of dispersant was only about 3.5% of the quantity of oil discharged (3.5bbl/100bbl oil) the oil plume extended less than 3 km from the spill site, whereas untreated slicks extended out to 10-15 km and occasionally as much as 80 km.

Such a dispersion of spilled oil has advantages in that, in addition to reducing the potential hazard to avifauna, it would also reduce the exposure potential to marine mammals surfacing in the area. In cases where water-in-oil emulsions are formed (high viscosity emulsions) McAuliffe (1977) contends that the application of sufficient chemical dispersants would prevent the formation of a "mousse" by converting it to an oil-in-water emulsion. The break-up of water-in-oil emulsions is further desirable as such formulations may tend to slow the process of "weathering" and result in the formation of "tar balls" which may strand on shore or intertidal areas, a process which McAuliffe (1977) noted would be further disadvantageous as such stranded globs of oil, in turn, weather more slowly than tar balls at sea.

Oil-in-water emulsions also do not tend to stick to mineral surfaces an effect which reduces the amount of sedimentation of the oil in mixing zones of high turbidity. Also, such dispersed oil would also probably tend to adhere to

intertidal areas less than untreated oils. Such a reduction of adhesion to surfaces contacting the emulsion could also possibly extend to sea birds and marine mammals which could reduce the impact of the oil should those animals become exposed to it. McAuliffe (1977) cites evidence of the successful use of dispersants in Europe over the past decade, but notes that the process of emulsification, dispersion and biodegradation are slower in cold, Arctic waters. With the increase of viscosity which occurs to oil in cold water the life of a slick may be longer than for warmer waters, although the half-life of slicks at 5°C in Cook Inlet have been observed to be less than 1 day (Kinney et al., 1969). Since the vapour pressure of a hydrocarbon will decrease by about 5% per degree Centigrade at cold sea water temperature ranges (McAuliffe, 1977) evaporative losses are also reduced. At the same time, diffusion and solution of oils into cold water proceed more slowly than in warmer waters as does biodegradation.

All these considerations argue for the judicious use of chemical dispersants in the Arctic regions. Any rapid capabilities to emulsify large volumes of oil would tend to reduce the physical contact risk to organisms from hypothetical, massive spills (particularly birds and marine mammals) and may tend to promote dispersion and biodegradation of the hydrocarbons.

8.5 REGULATORY CONCERNS

The Environmental Protection Service has recently opined that "The use of chemical agents should be regulated. Approvals should be made on a case-by-case basis weighing factors such as the type of dispersant used, sensitivity of nearby valued natural areas and the likelihood of success of alternative methods" (E.P.S., 1978). The agency also recommends that identification be made of specific coastal areas in which chemical agents of a specified type could be used so as to control the use of dispersant chemicals depending on the biotic resources of the area.

Petro-Canada will, therefore, undertake to develop a sector-by-sector evaluation, in concert with regulatory agencies, of specific areas of potential chemical useage which will be linked to the biological sensitivity of those areas (refer to section 4.1.).

Further, chemicals under consideration for potential use will be fully investigated as to their toxic, or potentially toxic, side or direct effects.

REFERENCES

Environmental Protection Service, 1978. A study of environmental concerns offshore oil and gas drilling and production. E.P.S. Ms. Rept., 2-EC-78-1, June, 1978.

Huang, C.P. and Elliot, H.A., 1977. The stability of emulsified crude oils as affected by suspended particles. In: Fate and effects of petroleum hydrocarbons in marine organisms and ecosystems. Permagon Press, Toronto. p.413-420.

Kinney, P.J., Button, D.K. and Schell, D.M.,1969. Kinetics of dissipation and biodegradation of crude oil in Alaska's Cook Inlet. Proc. Joint Conf. on Prevention and Control of Oil Spills. Amer. Pet. Inst., Wash. p. 333-340.

Loutfi, M.A., 1973. Canadian maritime oil exploration, exploitation and transport: A multidisciplinary study. McGill University. 364 p.

McAuliffe, C.D., 1977. Dispersal and alteration of oil discharged on a water surface. In: Fate and effects of petroleum hydrocarbons in marine organisms and ecosystems. Permagon Press, Toronto. 478 p.

Nelson-Smith, A. 1970. The problem of oil pollution of the sea. Adv. Mar. Biol., 8: 215-306.

Perkins, E.J. 1968. The toxicity of oil emulsifiers to some inshore fauna. Fla. Stud., 2(suppl.): 81-90.

Van Cleave, H.D., 1973. Spill prevention - Phase II. Proc. Joint Conf. on prevention and control of oil spills. Mar. 13-15, 1973, Wash. D.C., p. 27-30.

9.0 RESIDUAL IMPACTS

9.1 INTRODUCTION

The Environmental Assessment and Review Panel (EARP) Guidelines for preparation of an Environmental Impact Statement (1978) define "residual impacts" as those "environmental impacts that remain after all practical mitigating measures have been incorporated into the proposals. . ."

The classification of impacts has often formed the basis for impact assessments. Impacts which were classified as "major" have, from an ecological perspective, often been arbitrarily considered as having residual effects. While this may, indeed, be true concerning the catastrophic effects of a massive oil spill in the Arctic, such approaches may be misleading. For instance, although some predatory species may constitute a relatively small proportion of a regional community of animals they may exert a pivotal influence on the distribution and occurrence of prey species. If the predators are removed from the drastic system perturbations in prey populations may result from it. Hence, subtle impacts, occurring over long periods of time, may result in substantial changes in biota.

Here, it is considered that the degree of importance of a "residual impact", therefore, will be determined not so much by arbitrary definitions of the magnitude of impacts as by the effects, or potential impacts, on impacted communities of biota. The true measure of an "impact" and its residual, or lasting nature, is reflected in the biota and not necessarily in anthropocentric views of the magnitude of damage to the environment.

Such lasting, "residual" impacts may, therefore, potentially arise from many sources. While it is most probable that they would arise from massive, catastrophic incidents, such as tanker oil spills, subtle long-term inputs to ecosystems may also effect a lasting influence.

9.2 ROUTINE DRILLING AND ABANDONMENT

As noted in detail elsewhere (Section 5.0) it is not unreasonable to conclude that the disposal of drilling fluids and cuttings from the drilling of the exploratory wells will not result in any significant impact on the biota and benthos of Baffin Bay. Similar conclusions for more southerly regions have been reached elsewhere (Imperial Oil _et al_., 1978).

Experience and studies of intensive, prolonged drilling operations elsewhere in the world do not support concern regarding the proper disposal of drilling cuttings and fluids to oceanic areas. In the proposal for Baffin Bay the disposal of drilling fluids would be widely separated by location and events in the operations. Dispersion in the deep water would be rapid. There is no evidence to suggest that Arctic populations of marine organisms would be more susceptible to such dilute wastes than has been reported elsewhere from much more intensive operations such as offshore Louisiana, California, Alaska or the North Sea.

Support operations are not foreseen as causing measurable impacts in the course of normal operations. Helicopter and fixed-wing flight lines will be routed away from sensitive areas, such as large nesting bird colonies. The presence of the supply vessels, including icebreaker support, will not exert any more severe impacts than has become accepted standard practise in the high Arctic marine environment.

If the presence of the drillship influences marine mammals by way of noise or drilling effluents it is anticipated that these mobile populations would actively avoid the potentially offensive zones. The drilling zone is exceedingly small, relative to the total marine area available to marine mammals, so that enormous alternative areas would be available to them. Obviously, at the end of the drilling program (indeed, at the end of each drilling season) all the marine vessels will return from the north to southerly ports. Upon abandonment the drilling wells will be cemented and permanently sealed off according to the principles of best drilling practise.

The proposed supply barge would be moored in a suitable harbour location. A prime consideration would be to select mooring sites which would avoid disturbances to local animal populations.

In summary, the normal drilling operations, and the marine support activities associated with it, cannot be thought to exert residual impacts.

The socio-economic impact statement for the region is discussed in detail in Section 6 and work in progress is aimed at further defining residual impacts.

9.3 THE WORST-CASE - A MASSIVE BLOWOUT OF OIL

As noted elsewhere, the worst, catastrophic, eventuality which could arise from drilling in Baffin Bay would be an uncontrolled blowout of oil. It is highly unlikely that such an event would occur however, if it did, it seems reasonable to consider that it could be uncontrolled for a year before relief-well drilling could be started or completed.

While detailed studies on the routes and rates of oil dispersion from hypothetical disaster scenarios are in progress it is reasonable, as a worst-case, to assume that enormous, lasting damage would result to local sea bird colonies throughout the region. The effects on marine mammal populations is largely unknown, however, unless these animals could actively avoid the oil slick, mortalities could result. Oil reaching beaches could persist for considerable lengths of time, although in some cases this could be a largely aesthetic concern.

Elsewhere, discussion about the use of dispersants is set out as a preliminary elaboration of contingency plans against possible oil-spills. At the time of drilling Petro-Canada intends to have in place a comprehensive contingency plan. As dispersants are actively in development, it is possible that these chemicals may form the basis for the active dispersion of spilled oil. However, before such plans are finalized more research on the effectiveness and toxicity of these chemicals must be carried out in cold, Arctic waters.

REFERENCES

Environmental Assessment and Review Process. 1978. Guidelines for preparation of an environmental Impact Statement for Eastern Arctic offshore exploratory drilling. Ottawa, 22 pp.

Imperial Oil Ltd., Aquitaine Co. of Canada, Ltd., and Canada-Cities Service, Ltd., 1978. Environmental Impact Statement for exploratory drilling in Davis Strait Region.

10 GENERAL OVERVIEW SECTION THE BIOTA OF BAFFIN BAY

Without question, the greatest environmental impact on the biota of the Lancaster Sound - Baffin Bay region would result from the uncontrolled flow of oil directly upon, or eventually reaching, the surface of those waters.

The principal impacts of spilled oils result from either chemical toxicity of the oil and its components or from physical effects such as entanglement, coating or smothering. Ecological effects include such impacts as acute and sub-acute poisoning of marine species, including sublethal behavioral alterations, the physical disruption or alteration of intertidal or sub-littoral benthic communities and the contamination of vertebrate or invertebrate species caught for human consumption. The latter effect includes the tainting of flesh which affects palatability and, possibly, health. In addition to these effects there is also the possibility of aesthetic considerations deriving from the tarring of beach areas which may include the loss of biotic resources and the contamination of man-made structures and facilities.

In Arctic areas aesthetic considerations are often overlooked, however, near settlements such impacts would be considered as unacceptable. Similarly, in marine areas which include or infringe on proposed National Parks, National Landmarks or proposed ecological sites such aesthetic impingement may constitute a real threat.

Sea-birds are exceptionally susceptible to oil pollution. Indeed, large kills of birds are often the first superficial indication of an oil spill at sea. The oil affects the plumage of the birds by filling air spaces in the feathers so that the natural insulating capabilities are destroyed and water repellency is greatly reduced. Diving birds invariably suffer the heaviest mortalities around oil spills, particularly guillemots, razor-bills and cormorants. It has been reported that a spot of oil only 3 cm across on the breast of a sea-bird may be enough to eventually kill it. Such birds, as auks (which include guillemots), have low rates of reproduction and are relatively long-lived so that severe losses to colonies are replenished very slowly. Worse still, such drastic declines in populations may accelerate as the colony decreases in size as some species have proportionately less success at reproduction and feeding than do larger colonies.

Sea-birds are also susceptible to oil pollution because they tend to concentrate at locations which are suit-

able for breeding and which provide favourable oceanographic conditions for food. In restricting the often enormous single or mixed-species colonies to such areas of protected nesting sites and sufficient marine productivity aggregated distributions of the animals develop which, if heavily polluted by oil, renders significant proportions of the population open to contamination and, therefore, mortality.

Once oiled, the animals attempt to preen the substance from their feathers. Such preening activities may lead to secondary toxic or infectious effects resulting from the digestion of the oil. This, in turn, may lead to a reduction in the viability or hatching success of eggs because of oil contamination of the parent birds and the nest. There is evidence which indicates that bird mortality after oiling is often highest where temperatures are low and food-searching activity requires relatively large expenditures of energy.

While it may be true that a major oil spillage may exert a significant impact on marine bird colonies, the prospect of repeated exposures to oil probably represent a far greater hazard to such populations. For instance, the southernmost puffin colony in Europe, at the Sept Iles bird sanctuary, was severely depleted by the oil spill which resulted from the Torrey Canyon wreck in 1967 (over 95% of the birds were lost). By 1977 French authorities estimated that the colony had reached 1,200 birds, however, the Amoco Cadiz, which spilled 209,000 metric tons of Arabian crude oil along the coast of Brittany in 1978, further reduced the colony to 1 bird. The series of impacts from the oil spillages, although separated by a decade, has nevertheless all but annihilated this colony of marine birds.

Rehabiliation of oiled sea-birds has been singularly unsuccessful following major spills. It was estimated that out of 8,000 oiled birds recovered for cleaning after the Torrey Canyon spill only about 100 were thought to have survived. More recently bird cleansing techniques have been improved but they remain largely impractical for the Arctic. In the vicinity of Lancaster Sound alcids (black guillemot, dovkie and thick-billed murre), black-legged kittiwakes and fulmars would be most at risk from oil spills because of the amount of time that they spend in and upon the ocean.

These colonies of birds represent a large proportion of the total populations of the sea-bird species of the Canadian Arctic and of West Greenland (thick-billed murre colonies on Prince Leopold, Bylot and Coburg Islands represent up to 30% of the total of this species in eastern North

America). Thick-billed murre adults and their young eventually vacate their breeding sites in late August by swimming across Baffin Bay to west Greenland and comparable risks of exposure to spilled oil are posed again in the spring as the population returns. In some cases, the bird colonies of the Lancaster Sound region are presently under heavy pressure from impacts associated with salmon fisheries or hunting. As such, a large petroleum hydrocarbon release to surficial waters of the region at a critical time would incur a disastrous, massive mortality among the birds, particularly thick-billed murres. Of particular note here is the potential for a series of spills and the extreme additive effects of the impact on populations.

The insulative capacity of the fur of marine mammals is also reduced, as with bird plumage, when contacted by oil. There are, nevertheless, no cases reported in the literature of widespread mortalities of marine mammals which are caused by oil spills. However, such negative indications of impact do not necessarily indicate that there is not a deleterious effect of oils among marine mammals. It is enough to state that the full physiologic and ecologic effects on marine mammals of substantive spillages of oil at sea have yet to be fully assessed by science.

Lancaster Sound and Baffin Bay support large numbers of beluga (White Whale) and narwhal, over 33% and 85% of the North American populations occuring in these waters, respectively. Substantive concentrations of marine mammals including harp, bearded and ringed seals, walrus and polar bears also frequent the region. Large whales, bowhead and killer whale, also are known here the former being an endangered species. We can only conjecture as to whether or not these animals will actively avoid (or be able to avoid) large concentrations of oil and therefore the consequences of the contamination to widespread marine areas.

Oil spills at sea have not been observed to have caused widespread mortalities among adult fish populations although oil and oil-dispersant mixtures have been responsible for fish kills in localized areas. After oilspills in the Santa Barbara Channel, the Ekofisk blowout and after the Torrey Canyon disaster fish stocks were largely undamaged. However, sub-lethal affects such as the tainting of fish flesh by hydrocarbons may result from massive spills. Also, hydrocarbon residues may not necessarily be accompanied by taste and, therefore, may move throughout food webs. While mature fishes may avoid oil in the water, the eggs and larvae may haplessly contact the substance. Such a possibility may be enhanced through the formation of ice in Lancaster Sound

and by the intense interactions between the vertebrate and invertebrate fauna on the underice communities of algae, a zone of contact which would certainly be contaminated by an undersea spill of oil after freeze-up.

One important point which is often not made in the assessment of impacts of pollutants on ecosystems, in particular for animal populations, is that attention must always be focussed on the impact of the pollutant on the least resistant portion of the life cycle of these animals. It is for this reason that one must view laboratory toxicity testing with caution before making extrapolations to communities in the field. Susceptibility, the potential duration of exposure to the pollutant and the numbers of the community which contact it must all be assessed in such hypothetical considerations. The complexity of the subject, regarding our ability to make experimentally, verifiable predictions of the impact of the pollutant, becomes even more apparent when one begins to consider sub-lethal effects and habitat disruptions on highly migrant populations. Scientists are only just beginning to be able to approach such questions.

Lower organisms such as shellfish, oysters and clams are known to suffer inimicable effects from oils and tainting of animals, such as oysters, has known to result from encounters with as little as 0.01 ppm of oil. Crustaceans and molluscs are usually more susceptible to oils in the immature stages and smothering effects of attached crustacea by heavy concentrations of oil is well known from tanker spills.

Intertidal benthic communities of animals may be severely damaged by oil which becomes stranded in these areas. In general it could be said that heavily polluted areas initially undergo a reduction in the number of species present followed by an increase in resistant organisms.

As a result of the severe scouring effects from ice on arctic beaches the benthic fauna is generally reduced in these zones, if not entirely absent. The presence of ice-ridges on low-energy beaches may, however, allow spilled oil to be retained there for considerable length of time. On the other hand, anchor ice which may persist in sheltered coastal zones may prevent the oil from reaching the beach, trapping it instead, at considerable distances from the land and acting, in effect, as a natural "oil boom".

Planktonic species exhibit a sensitivity to oil which may be highly variable, depending on factors such as species and the type of oil which they may contact. Whole-

sale, massive mortalities of zooplankton resulting from oil pollution events have not been reported, however, some zooplankton species may be sensitive to low concentrations of oil, especially the larval stages. That the zooplankton may injest small particles of oil is not surprising as most species are filter feeders on suspended particulates in the upper layers of water. Some authors have suggested that such feeding mechanisms may remove significant quantities of oil (as small droplets ranging in size from 5 microns to 2 mm) from the water column, some of which may be sedimented out as faecal pellets.

In light of the widespread distributions of planktonic communities, it is doubtful that even massive serious oil spills would greatly upset regional populations of the plant or animal species. Assertions such as this must, however, be qualified by the fact that a recovery from a large oil spill would probably be facilitated by regional currents which would transport and dilute the petroleum hydrocarbons while allowing repopulation in areas where planktonic populations were adversely affected. Similarly, oceanic bacterial populations may be altered in localized areas of hydrocarbon occurrences, but such alterations may be an indication of bacterial assimilation of components of oil.

In summary, it must be recognized that almost all marine biological production occurs in the upper 50-100 metres of the sea. In these upper layers of water phytoplankton, zooplankton and many species of fish and marine mammals cohabit, feed and reproduce. Hydrocarbon spills will, by definition, impinge upon the areas of the ocean which are characterized by the greatest biological activity. This threat is further compounded by the presence of seabirds who migrate through and feed in the upper layers of this marine habitat.

It has been noted in the literature that oiled marine environments may recover from such pollution in from 5 to 15 years, although we still lack reliable data from the high Arctic marine environment. The mechanisms for recovery include wave action on beaches and the processes of erosion which occurs there and biological conversion, including microbial degradation. We do not understand how Arctic bird colonies or marine mammal populations will interact with and recover from massive oil spills except to say that based upon the experience gained in other areas of the world the Arctic marine bird colonies, at least, may be seriously disrupted or destroyed.

APPENDIX I

SUMMARY OF 1978 FIELD STUDIES

1. INTRODUCTION

Following the announcement in November 1977 of the Eastern Arctic Marine Environmental Studies, the Proponent carried out extensive studies on the physical and biological environment of Lancaster Sound and Baffin Bay in 1978. These studies will be continued in 1979 and will culminate with an Environmental Impact Statement submitted to the appropriate regulatory agencies and reviewed by the Environmental Assessment and Review Process (EARP) of the Federal Government.

Presently, the design for the 1979 field season is in preparation and the bulk of the field studies are expected to resume in the spring and continue on until late fall. A summary of the studies carried out in 1978 is detailed below.

2. BIOLOGY AND ECOLOGY

a) Aerial Transects

Systematic aerial transects were carried out to determine in detail the distribution and migration patterns of marine birds and mammals in the Lancaster Sound and Northern Baffin Bay region (see Section 4.2). These were conducted by L.G.L. Ltd. of Toronto, using Petro-Canada's Twin Otter. Survey flights were designed with the maximum effort covering the migrations into and out of the survey regions and with a reduced effort in mid-summer when animal populations were relatively stable. The program commenced May 1 and continued through until October 10.

b) Marine Ecology

The feeding habits of fish, birds and mammals and the significance of lower forms of life in the food chains were studied by biologists based on the m.v. Theron, m.v. Gulf Star and in the local communities. Birds were recovered from their offshore feeding areas and their stomach contents were examined. Systematic vertical and horizontal tows were made for plankton and fish with particular emphasis on the ice edge regions where fish, mammals and birds concentrate to feed.

The m.v. Gulf Star supported detailed studies of the shoreline areas together with geologists of the Geological Survey of Canada to determine the sensitivity and vulnerability of selected areas to a potential oil spill. Samples of inshore marine life were collected using bottom trawls, grabs and plankton hauls. SCUBA divers made undersea observations and collected samples of bottom fauna.

c) Bird Studies - Coburg Island, Cape Hay and Prince Leopold Island

Studies covering the three main marine bird colonies in the area were expanded when it became apparent that in 1978 was an unusually severe ice year. As a result, marine birds were unable to obtain their normal food supply during late spring and early summer. The Murre colonies at the three localities were approximately 3 weeks late in egg laying and the young from the Prince Leopold Island colony were observed transiting large ice flows on their migration eastward out of Lancaster Sound (pers. comm. D. Nettleship). The Kittiwakes which share the same colonies gave up egg laying efforts early in the season (less than 1% had eggs). In summary, it appears that 1978 was a disastrous year for colonial seabirds in the Baffin Bay region. As such, the data will form a valuable point of reference against which future population fluctuations may be compared, especially in reference to proposed industrial activities.

d) Resource Harvest Studies

A collection of resource harvesting statistics and mammal samples were obtained at Pond Inlet and Grise Fiord by the local Hunters and Trappers Association under the guidance of professional biologists on contract to the Proponent.

3. PHYSICAL OCEANOGRAPHY

These studies were conducted from the m.v. Theron by scientists from Arctic Sciences Ltd., the main components being:

a) Measurement of subsurface currents in Baffin Bay - Lancaster Sound using 14 current meter moorings throughout the summer. All moorings were recovered by October

5th and seven replaced for the collection of winter and spring data. Each mooring deployed between 3 and 5 current meters which automatically recorded current speed and direction.

b) Water level gauges

Two of which were situated at the entrance to Lancaster Sound to record the tidal components.

c) Surface Drift Buoys

These were released from the m.v. Theron and tracked via satellite to give detailed information on surface currents.

d) Oil Spill "Follower" Buoys

These were set adrift at the proposed drill-sites and tracked by the ship and helicopter, to simulate the fate and spread of a surface oil slick.

e) Water Masses

As defined by salinity and temperature, these bodies of water were traced by a systematic C.T.D. profiling sampling grid made up of approximately 80 stations which were monitored 3 times each during the season.

4. <u>ICE AND ICEBERG STUDIES</u>

a) Iceberg and Iceflow Overflights

Prescribed tracks through the survey area were flown daily (weather permitting) with a Britain-Norman Islander equipped with a forward-looking weather radar and a low level vertical camera from July 2 to October 10 by Norcor Engineering Ltd.

A data logging system obtained a photographic record of the radar display with a marginal printout of time and "Global Nav" position co-ordinates. Similar marginal notations were recorded on the iceberg which were used later in identifying vertical photographs.

In excess of 600 targets were sighted during July and August. At one point in the observations in excess of

100 icebergs were sighted in the survey area and were estimated to range in size from 1/2 million to 50 million tons. Information from these flights were passed to the 2 radar camps for more detailed continuous tracking of identified icebergs.

b) Radar Tracking of Icebergs

Two radar camps were sited at Cape Fanshawe and Cape Sherard, respectively. The former was operated by Nordco Ltd., and the latter by Seakem Ltd. Both stations made a photographic record of the radar screen every 20 minutes. From these photographs target identification and correlation gave the tracking record of detected icebergs and large flows. One of the main features noted was the erratic behaviour of icebergs. Many bergs reversed their general direction and moved north through the southern drilling site.

c) Iceberg Profiling

These studies were carried out by ICE, Ltd. Approximately 40 icebergs were sounded by helicopter-mounted sonar. These measurements will provide details of the underwater drafts of individual bergs, their overall mass and indicate the depths at which ice scour can be expected. The studies will also provide data toward an assessment of the feasibility of towing or deflecting icebergs of various shapes and sizes.

d) RAMS buoys on Icebergs

10 RAMS buoys were placed on selected icebergs and then tracked by satellite with a positional accuracy of ± 1 mile.

5. METEOROLOGY

a) Field Synoptic Studies

Synoptic weather observations done at 3 or 6 hour intervals were recorded on the m.v. Theron, mv. Gulf Star and m.v. Researcher while ships were in the area. Other observations were made at the land stations at Hope Monument, Cape Fanshawe, Cape Sherard and Cape Liverpool. The latter two were automatic recording stations, while the remainder were visual observations.

These data are being annotated onto existing A.E.S. surface pressure maps and may be used for surface wind windcasting.

b) Climatology

The Atmospheric Environment Service at Downsview, Ontario are undertaking a historical climatological study of the region on contract to the Proponent.

6. GEOMORPHOLOGY

a) Photographic research

A study is being made of the existing aerial photographic coverage of the coastal zones throughout the survey region. This research is being augmented by additional photography and observation of coastal regions so as to amplify and verify the photographic interpretation work for the area.

b) Coastline Geomorphology

These studies are being conducted by geologists from the Geological Survey of Canada to examine in detail selected sites from Devon Island south to Bylot and Baffin Islands in conjunction with a biologists.

Shoreline morphology and inshore bathymetry and shallow seismic profiling studies were conducted as well as extensive diving operations in depths up to 100 ft. at 5 coastline stations (2.b.).

These three studies will contribute towards a coastline classification atlas showing geomorphological divisions and biologically important areas which will be a major component of the oil spill contingency plan now in operation.

APPENDIX 2

Table of Contents - Preliminary

Socio-Economic Impact Statement

6.0 This table of contents is in the view of the Proponent very preliminary, and in keeping with our philosophy with respect to Community involvement, is subject to change following our discussions with community leaders and special interest groups.

6.1 History of the region - a brief overview of the region from the earliest contact with European explorers to the present day.

6.2 The Region Today - focusing on current status of the region.

6.3 Pond Inlet Today - a more detailed review of Pond Inlet where the Proponent expects the major impact to occur.

6.4 The Proposal and Petro-Canada Policy

1. Restatement of relevant aspects of the proposal.

2. Restatement of company policy.

3. Company policy with respect to evaluation of impacts.

6.5 Primary Impacts - the Region: Identification of Potential Impacts, Proposed Mitigation Measures and Residual Impacts. The Proponent is of the view that decisions will be made with respect to residual impacts only and therefore the major focus of attention will be on those impacts.

6.5.1 Wildlife Harvests in event of a blowout.

6.5.2 Scheduled Air Services.

6.6. Pond Inlet: The identification of Potential Impacts, Proposed Mitigation Measures and Residual Impacts. The Proponent is of the view that decisions will be made with respect to residual impacts only and therefore major focus of attention will be on those impacts.